

Transactions of the Royal Society of South Australia Incorporated

INCORPORATING THE

Records of the South Australian Museum

Contents

Berge, J. & Vader, W. Description of two new and unusual stegocephalid species (Crustacea: Peracarida: Amphipoda: Stegocephalidae) from Heard Island and the East China Sea	1
Jennings, J. T., Austin, A. D. & Stevens, N. B. Species of the Wasp genus <i>Aulacus</i> Jurine (Hymenoptera: Aulacidae) endemic to South Australia	13
Turner, D. & Conran, J. G. The reproductive ecology of two naturalised <i>Erica</i> species (Ericaceae) in the Adelaide hills: the rise and fall of two 'would-be' weeds?	23
Zbik, M. & Pring, A. The Myrtle Springs meteorite: a chondrite (H4) from South Australia	33
Leppard, P. I., Tallis, G. M. & Pearce, C. E. M. Expected lifetime in South Australia 1841 – 1996	37
Riley, I. T. & Bertozzi, T. Variation in sex ratios in four <i>Anguina</i> (Nematoda: Anguinidae) species	43
Smales, L. R. <i>Syphacia</i> (<i>Syphacia</i>) <i>australasiensis</i> sp. nov. (Nematoda: Oxyuridae) from <i>Rattus leucopus</i> (Muridae) from Papua New Guinea and Australia	47
Jones, H. I. Gastric nematodes, including a new species of <i>Abbreviata</i> (Nematoda: Physalopteridae) from the mangrove monitor <i>Varanus indicus</i> (Reptilia: Varanidae)	53
Parsons, R. F. Enrichment-planting of the woody climbers <i>Marsdenia australis</i> and <i>Rhyncharrhena Linearis</i> in north-western Victoria	61
Spratt, D. M. & Hobbs, R. P. <i>Breinlia</i> (<i>Breinlia</i>) <i>ventricola</i> sp. nov. (Nematoda: Filarioidea) from the heart of the red kangaroo, <i>Macropus rufus</i> , in Western Australia	67
Phillott, A. D. & Elsmore, S. A. M. Black Noddies (<i>Anous minutus</i>) and Wedge-tailed Shearwaters (<i>Puffinus pacificus</i>) as potential hosts for fungi invading sea turtle nests at Heron Island, Queensland	73

TRANSACTIONS OF THE

**ROYAL SOCIETY
OF SOUTH AUSTRALIA**

INCORPORATED

INCORPORATING THE

Records of the

South Australian Museum

VOL. 128, PART 1

EDITORIAL

This is the first issue of the *Transactions of the Royal Society of South Australia* to incorporate the *Records of the South Australian Museum*. The *Transactions* have appeared uninterruptedly for 127 years, publishing good science from and for southern Australia and the world, and the *Records* have a similar record of achievement over 86 years. Why have the Society and the Museum merged these two successful journals, each with its proud record?

The simple answer is that we believe that a single journal produced by the two institutions, which have many other beneficial linkages, can be better scientifically, can reach a bigger audience and can offer scientists a better platform for their research. In some fields, such as taxonomy, there has been much overlap, in others such as anthropology, little overlap in recent years, so that there is much complementary strength in the two journals.

What we have done so far is simply to merge the journals and to plan to send the merged *Transactions* out to the subscribers to both journals. For this first year, there will be two issues. Future changes will depend particularly on contributors and readers, the two groups who make or break any journal. If we find strong authorial support, we shall need to consider more frequent publication, with all the benefits and costs inherent in such a change. Or we may find that there is a need to divide the journal into parts for readers with different interests, though for many (such as the current editor) this would be a step with the huge disadvantage of no longer providing a journal for generalist specialists with interests in all aspects of science as it applies to southern Australia and related regions. The current issue, covering plant ecology, threatened species, parasitology, taxonomy, population science, and earth science, typifies this breadth and strength within the breadth.

The future is in your hands. Support the merged *Transactions* as readers and contributors, and it will go from strength to strength.

Oliver Mayo
Editor, for the Editorial Board

TRANSACTIONS OF THE ROYAL SOCIETY OF SOUTH AUSTRALIA INC.

CONTENTS, VOL. 128, 2004

PART 1, 31 MAY, 2004

Berge, J. & Vader, W.	Description of two new and unusual stegocephalid species (Crustacea: Peracarida: Amphipoda: Stegocephalidae) from Heard Island and the East China Sea	1
Jennings, J. T., Austin, A. D. & Stevens, N. B.	Species of the Wasp genus <i>Aulacus</i> Jurine (Hymenoptera: Aulacidae) endemic to South Australia	13
Turner, D. & Conran, J. G.	The reproductive ecology of two naturalised <i>Erica</i> species (Ericaceae) in the Adelaide hills: the rise and fall of two 'would-be' weeds?	23
Zbik, M. & Pring, A.	The Myrtle Springs meteorite: a chondrite (H4) from South Australia	33
Leppard, P. I., Tallis, G. M. & Pearce, C. E. M.	Expected lifetime in South Australia 1841 – 1996	37
Riley, I. T. & Bertozzi, T.	Variation in sex ratios in four <i>Anguina</i> (Nematoda: Anguinidae) species	43
Smales, L. R.	<i>Syphacia</i> (<i>Syphacia</i>) <i>australasiensis</i> sp. nov. (Nematoda: Oxyuridae) from <i>Rattus leucopus</i> (Muridae) from Papua New Guinea and Australia	47
Jones, H. I.	Gastric nematodes, including a new species of <i>Abbreviata</i> (Nematoda: Physalopteridae) from the mangrove monitor <i>Varanus indicus</i> (Reptilia: Varanidae)	53
Parsons, R. F.	Enrichment-planting of the woody climbers <i>Marsdenia australis</i> and <i>Rhyncharrhena Linearis</i> in north-western Victoria	61
Spratt, D. M. & Hobbs, R. P.	<i>Breinlia</i> (<i>Breinlia</i>) <i>ventricola</i> sp. nov. (Nematoda: Filarioidea) from the heart of the red kangaroo, <i>Macropus rufus</i> , in Western Australia	67
Phillott, A. D. & Elsmore, S. A. M.	Black Noddies (<i>Anous minutus</i>) and Wedge-tailed Shearwaters (<i>Puffinus pacificus</i>) as potential hosts for fungi invading sea turtle nests at Heron Island, Queensland	73

PART 2, 30 NOVEMBER, 2004

Appan, A., Bergfeld, J. & Beveridge, I.	New species of parasitic nematodes from macropodid marsupials in Western Australia - - - - -	77
Hammer, M. P. & Walker, K. F.	A catalogue of South Australian freshwater fishes, including new records, range extensions and translocations - - - - -	85
Watts, C. H. S. & Humphreys, W. F.	Thirteen new Dytiscidae (Coleoptera) of the genera <i>Boongurrus</i> Larson <i>Tjirtudessus</i> Watts & Humphreys and <i>Nirripirti</i> Watts & Humphreys, from underground waters in Australia - - - - -	99
Watts, C. H. S.	Revision of Australian <i>Scirtes</i> Illiger and <i>Ora</i> Clark (Coleoptera: Scirtidae) -	131
Hodda, M.	Characteristics of an Australian population of <i>Paraxonchium orthodon</i> (Loof 1964) Altherr & Loof 1969, with a note on evolution and biogeography of the subfamily Paraxonchiinae (Nematoda, Dorylaimida, Aporcelaimidae) - -	169
Beveridge, I. & Johnson, P. M.	Cestode parasites of tree kangaroos (<i>Dendrolagus</i> spp.: Marsupialia), with the description of two new species of <i>Progamotaenia</i> (Cestoda: Anoplocephalidae) - - - - -	175
Faucheux, M. J.	Antennal sensilla of <i>Sabatinca sterops</i> Turner (Lepidoptera: Micropterigidae)	187
Barker, S.	Twelve new species of Australian Buprestidae (Coleoptera) and new synonymy - - - - -	195
Womersley, H. B. S.	Additions to the Marine Algal Flora of southern Australia - - - - -	205
Smith, B. P. C. & Kokkinn, M.	The use of emergence as an end-point for sediment toxicity tests using the Australian chironomid <i>Chironomus maddeni</i> - - - - -	213
Barton, P. S., Aberton, J. G. & Wishart, E.	Spatial and temporal distribution of <i>Culex australicus</i> Dobrotworsky and Drummond and <i>Culex globocoxitus</i> Dobrotworsky (Diptera: Culicidae) at the Gippsland Lakes in eastern Victoria - - -	219
Williams, C. R., Snell, A. E. & Kokkinn, M. J.	Studies of temporal host-seeking patterns of <i>Culex Annulirostris</i> (Diptera: Culicidae): a comparison of methods and populations	225
Gibbs, S. E., Kemper, C. M., Byard, R. W. & Long, M.	Deaths of killer whales (<i>Orcinus orca</i>) in South Australia and implication of human interaction - - - - -	231
Hinchcliffe, J. & Conran, J. G.	The Tennyson sand dunes: vegetation structure and conservation status - - - - -	239
Smith, B. B. & Walker, K. F.	Reproduction of common carp in South Australia, shown by young-of-the-year samples, gonadosomatic index and the histological staging of ovaries - - - - -	249
<i>Brief Communications:</i>		
Souter, N. J.	A comparison among three artificial substrates for aquatic macroinvertebrate sampling - - - - -	259
Matthews, E. G.	New synonymy and new names in Australian Tenebrionidae (Coleoptera) -	261

**DESCRIPTION OF TWO NEW AND UNUSUAL STEGOCEPHALID
SPECIES (CRUSTACEA: PERACARIDA: AMPHIPODA:
STEGOCEPHALIDAE) FROM HEARD ISLAND AND
THE EAST CHINA SEA**

By J. BERGE¹ & W. VADER²

Summary

Berge, J. & Vader, W. Description of two new and unusual stegocephalid species (Crustacea: Peracarida: Amphipoda: Stegocephalidae) from Heard Island and the East China Sea. Trans. R. Soc. S. Aust. 128(1), 1-11, 31 May, 2004.

Two new stegocephalid (Amphipoda) species are described: *Mediterexis macho* and *Stegocephalina wolf*. One of the species, *Mediterexis macho*, is the very first record of a stegocephalid from the China Sea, whereas *Stegocephalina wolf* was collected North of Heard Island in the Southern Ocean.

Key Words: Amphipoda, Stegocephalidae, *Mediterexis macho* sp. nov., *Stegocephalina wolf* sp. nov.

DESCRIPTION OF TWO NEW AND UNUSUAL STEGOCEPHALID SPECIES (CRUSTACEA: PERACARIDA: AMPHIPODA: STEGOCEPHALIDAE) FROM HEARD ISLAND AND THE EAST CHINA SEA.

by J. BERGE¹ & W. VADER²

Summary

BERGE, J. & VADER, W. Description of two new and unusual stegocephalid species (Crustacea: Peracarida: Amphipoda: Stegocephalidae) from Heard Island and the East China Sea. *Trans. R. Soc. S. Aust.* 128(1), 1-11, 31 May, 2004.

Two new stegocephalid (Amphipoda) species are described: *Mediterexis macho* and *Stegocephalina wolf*. One of the species, *Mediterexis macho*, is the very first record of a stegocephalid from the China Sea, whereas *Stegocephalina wolf* was collected North of Heard Island in the Southern Ocean.

KEY WORDS: Amphipoda, Stegocephalidae, *Mediterexis macho* sp.nov., *Stegocephalina wolf* sp.nov.

Introduction

The Antarctic fauna of stegocephalid species was reviewed by Berge *et al.* in 2000, in which a total of 19 species were recognised. Since then two additional stegocephalid species have been recorded from the area, excluding the new species *Stegocephalina wolf* reported herein. Thus, the Antarctic stegocephalid fauna currently consists of 22 known species belonging to 11 genera. The second new species herein described, is the first record of a stegocephalid species from the China Sea.

A phylogenetic analysis of the family Stegocephalidae was presented as part of a recent revision of the group (Berge & Vader 2001). Based upon this analysis, a new classification at the generic level was outlined. As the classification at both generic and subfamily levels falls outside the scope of this paper, the two new species (*Mediterexis macho* sp.nov. and *Stegocephalina wolf* sp.nov.) described herein are treated within the framework of that classification. Especially for *Mediterexis macho*, the generic position may well be altered in the future (see also below).

Material and Methods

This study is based upon material from the South Australian Museum (SAM). All dissected appendages were mounted in polyvinyl-lactophenol and stained with rose-bengal. These appendages were drawn using a Leica compound microscope equipped with a drawing-tube, while the habitus-drawings were

made using a Leica dissecting microscope. Mature and immature females were distinguished from males by the presence of oostegites. The classification of setae and setae-groups follows that of Berge (2001). All scales attached to the figures are 0.1 mm unless otherwise stated.

Symbols

A1-2: Antenna 1-2; EP3: Epimeral plate 3; IP: Inner plate; L: Labium; LBR: Labrum; LMND: Left mandible; MX1: Maxilla 1; MX2: Maxilla 2; MXP: Maxilliped; OP: Outer plate; P1-7: Pereopods 1-7; PLP: palp; RMND: Right mandible; ST: Setal teeth on the first maxilla; T: Telson; U1-3: Uropods 1-3.

Results and Taxonomy

The present study is based entirely on material provided from the collections of the South Australian Museum. The material comprised, in addition to the two new species reported herein, a total of 3 species; *Glorandaniotes sandroi* Berge & Vader, 2003a, *Parandania boeckii* Stebbing, 1888 and *Tetradeion crassum* (Chilton, 1883). The three above mentioned species were all found in Australia, whereas the two remaining, *Mediterexis macho* sp.nov. and *Stegocephalinae wolf* sp.nov., were collected from the East China Sea and Heard Island, respectively.

Key to the 22 species known from the Antarctic and sub-Antarctic regions:

1. Pereopod 6 basis expanded, posterior margin convex (2)
- Pereopod 6 basis weakly expanded, posterior margin straight or concave (17)
- Pereopod 6 basis not expanded, about as broad as pereopod 5 basis (21)

¹ UNIS, Department of Biology, Pb 156, 9170 Longyearbyen, NORWAY. Email: jorgen.berge@unis.no

² Tromsø Museum, Dept of Zoology, University of Tromsø, 9037 Tromsø, NORWAY. Email: wim@imv.uit.no

2. Uropod 3 rami obsolescent or absent
Stegocephalina pacis
- Uropod 3 both rami well developed (3)
3. Telson entire (4)
- Telson cleft (8)
4. Antennae subequal (5)
- Antenna 2 elongate, longer than antenna 1
Parandania boeckii
5. Antenna 1 flagellum with 5 articles *Andaniexis olli*
- Antenna 1 flagellum more than 10 articles (6)
6. Antennae elongate *Parandania boeckii* (juveniles)
- Antennae not elongate (7)
7. Labrum symmetrical, both lobes strongly reduced *Parandania gigantea*
- Labrum asymmetrical, right lobe large, left lobe strongly reduced *Parandania nonhiata*
8. Rostrum weakly developed (9)
- Rostrum large and distinct *Stegocephalus rostrata*
9. Coxa 1 anterior margin convex (10)
- Coxa 1 anterior margin with a deep invagination *Stegocephalus waitlingi*
10. Telson longer than broad, triangular and pointed (11)
- Telson about as long as broad, not pointed (13)
11. Mouthparts not elongate and not forming a conical bundle (12)
- Mouthparts elongate, forming a conical bundle projecting well below coxae *Stegocephalina wolf* sp. nov.
12. Epimeral plate 3 posteroventral corner acute, with one notch *Stegocephalus kergueleni*
- Epimeral plate 3 posteroventral corner rounded, crenulated Genus *Pseudo* (see below)
13. Antenna 1 flagellum article 1 shorter or about as long as peduncle (14)
- Antenna 1 flagellum article 1 distinctly longer than peduncle (15)
14. Coxae 1-3 broad and overlapping, coxa 4 posterior lobe exceeding pereon segment 6 *Stegosoladidus antarcticus*
- Coxae 1-3 narrow, not overlapping, coxa 4 posterior lobe not exceeding pereon segment 6 *Andaniotes linearis* (immature)
15. Maxilla 2 gaping and geniculate, epimeral plate 3 posteroventral corner produced and with teeth Genus *Pseudo* (see below)
- Maxilla 2 not gaping and geniculate, epimeral plate 3 posteroventral corner weakly produced, without teeth (16)
16. Antenna 1 flagellum with 4 articles *Andaniotes pseudolinearis*
- Antenna 1 flagellum with more than 10 articles *Parandania boeckii*
17. Uropod 3 outer ramus 2-articulate (18)
- Uropod 3 outer ramus 1-articulate *Stegosoladidus ingens*
18. Telson cleft (19)
- Telson entire *Andaniella integripes*
19. Pereopod 6 basis posteromedially with 2-3 long plumose setae (20)
- Pereopod 6 basis posteromedially with a row of short robust setae *Andaniotes linearis*
20. Coxae 1-3 broad and overlapping, maxilliped inner plate with 2 nodular setae *Stegosoladidus debroyeri*
- Coxae 1-3 narrow, not overlapping, maxilliped inner plate with 4 nodular setae *Andaniotes pooh*
21. Telson entire (22)
- Telson cleft (23)
22. Telson short, pereopod 4 subchelate, pereopod 7 well developed *Parandaniexis dewitti*
- Telson long, pereopod 4 simple, pereopod 7 reduced *Tetradeion crassum*
23. Epistomal plate large, conspicuous *Austrophippisia unihamata*
- Epistomal plate absent *Schellenbergia vanhoeffeni*

Remarks to the key

The key is rewritten and updated from that presented by Berge *et al.* (2000) to include both the new *Stegocephalina wolf* sp. nov. (see below) and the two *Pseudo* Berge & Vader, 2001 species that were described, but not given a formal scientific name in Berge & Vader (*submitted*). Furthermore, all generic names in the key are updated according to the outlined classification of all stegocephalid taxa in the revision of the family by Berge & Vader (2001).

Subfamily Andaniexinae Berge & Vader, 2001.

Genus *Meditexis* Berge & Vader, 2001.

Meditexis macho sp. n. (Figs 1-3)

Holotype

Male, 4 mm (SAM C6054), East China Sea (30° 06' N, 130° 35' E), 02.07.1966. Unique.

Etymology

The name refers to its densely setose peduncles of the antennae, compared to all other stegocephalid taxa.

Diagnosis

Antennae subequal, peduncles setose, accessory flagellum longer than antenna 1 flagellum article 1. Epistome laterally produced, epistomal plate present. Mandibles with transverse smooth incisors, left

¹ The validity of this genus is discussed in Berge & Vader (*submitted*). To avoid any nomenclatory complications, the classification according to Berge & Vader 2001 is utilised.

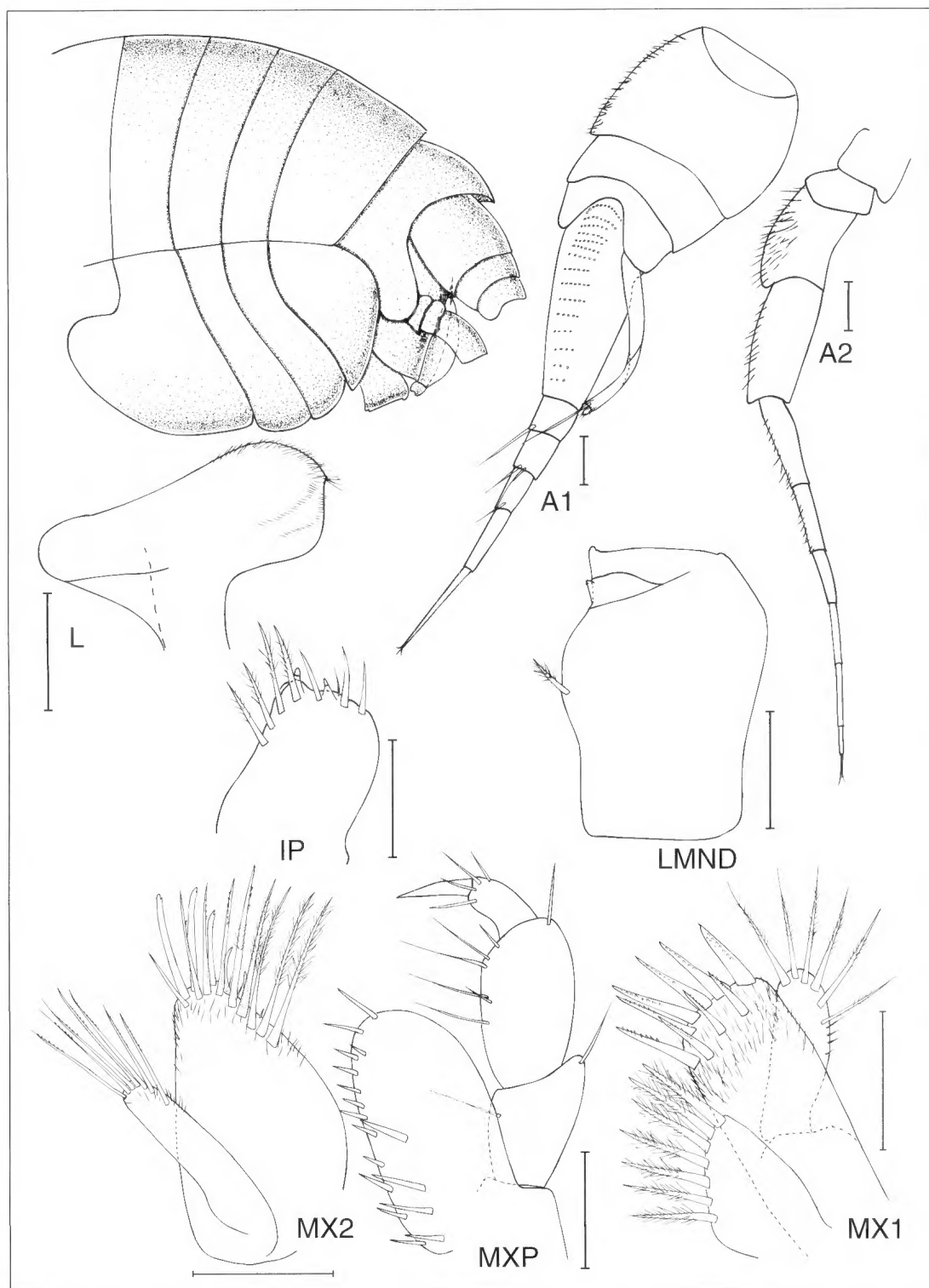


Fig. 1. *Mediterexis macho* sp.nov. Holotype.

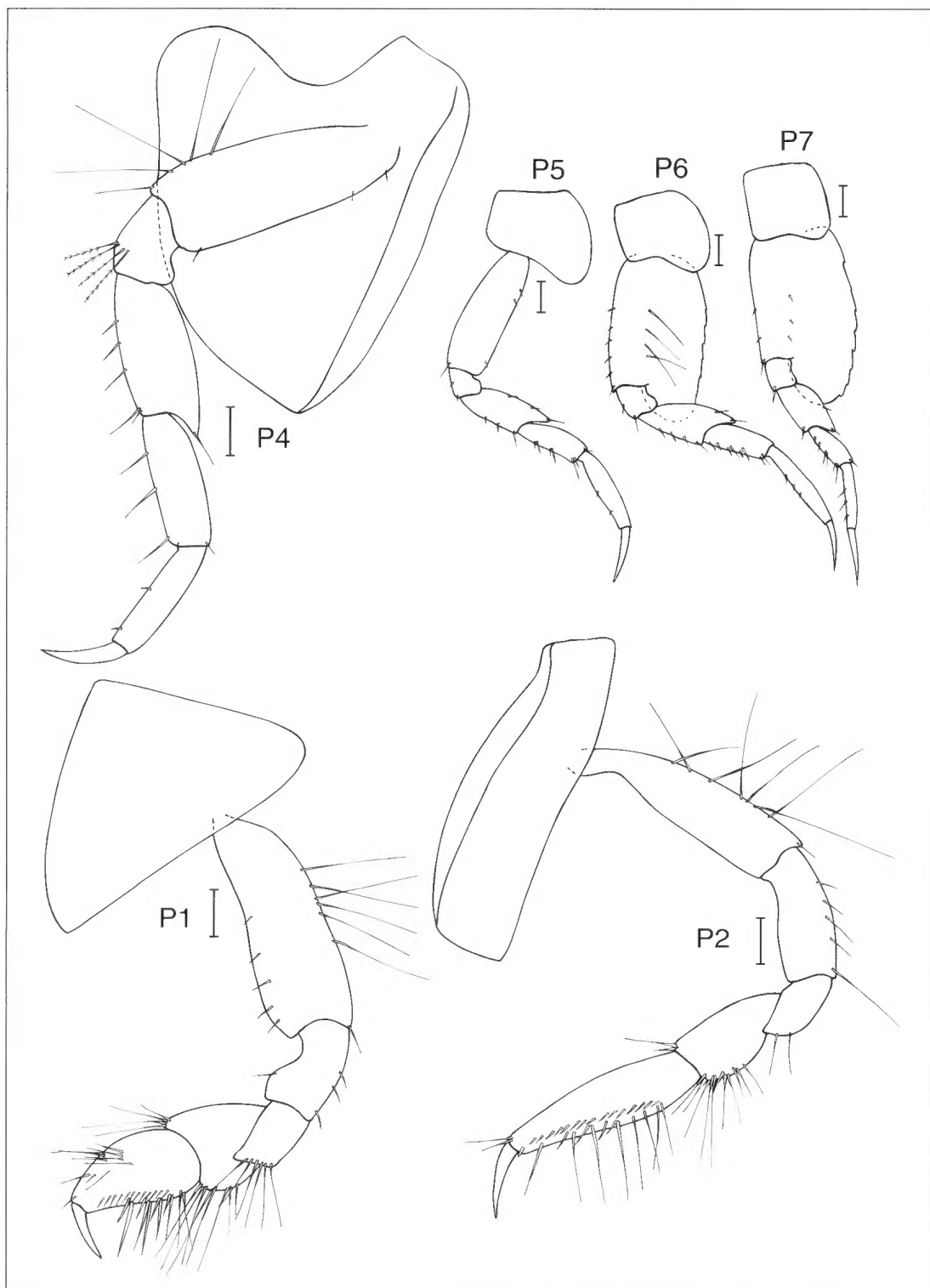


Fig. 2. *Mediterexis macho* sp. nov. Holotype.

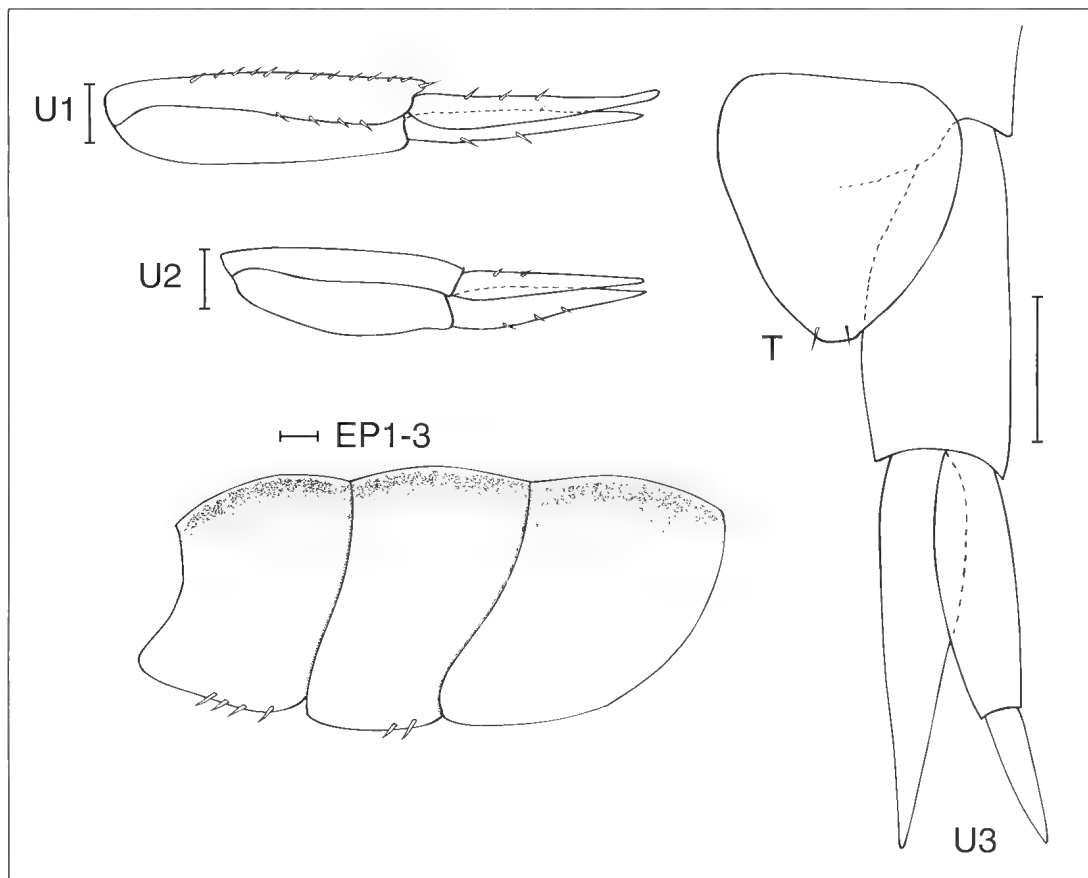


Fig. 3. *Mediterexis macho* sp. nov. Holotype.

lacinia mobilis weakly toothed. Maxilla 2 not gaping and geniculate. Labrum shorter than broad. Pereopod 6 basis posteriorly conspicuously expanded. Uropod outer ramus two-articulate. Telson entire.

Description

Head: Head retractable under pereonite 1. Rostrum rudimentary.

Antennae: Accessory flagellum longer than flagellum article 1, articulation present. Antenna 2 peduncle article 3 short, about as long as broad. Peduncle article 4 shorter than article 5.

Epistome: Epistome laterally produced and rectangular, with a long ridge on each side. Epistomal plate (medial keel) produced into a small elongate medial ridge covering the entire epistome.

Mouthparts: Mouthparts not elongate.

Mandibles with incisor transverse, smooth. Left lacinia mobilis present, weakly toothed and distally not produced.

Maxilla 1 palp articulation absent, distally with long pappose setae. Outer plate distally rounded, ST

in a 6/3 arrangement with two parallel rows: First row with ST 1-5 present, ST 6 absent and ST 7 present. Second row with ST A-C present. Inner plate with shoulder weakly developed, setae pappose.

Maxilla 2 outer plate not gaping and geniculate, setae distally straight. Inner plate with setae-row A and B appressed. Row B with first 3 setae differentiated from the other setae. Row C present, row D absent.

Maxilliped palp 4-articulate, article 2 not produced distally. Articles 1-3 with long slender setae. Inner plate distally with inner corner weakly produced, 2 nodular setae present. Outer plate with inner and outer setae-row present, both with robust slender setae. Distal setae-group absent.

Labrum shorter than broad, both lobes reduced.

Labium distally broad, distal finger absent.

Pereopods and coxae: Coxal plates and basis of the pereopods smooth. Coxae 1-3 contiguous.

Pereopod 1 coxal plate about as deep as basis, basis anterior margin weakly expanded. Pereopod 1

propodus subovate, posterior submarginal row of setae present.

Pereopod 2 ischium elongate, distal posterior margin without plumose setae. Propodus subrectangular, posterior submarginal row of robust setae present.

Pereopod 4 coxa locking-structure absent. Basis with long setae on posterior margin, distally without plumose setae. Ischium with long plumose setae on distal posterior margin.

Pereopod 6 basis posteriorly expanded, medially with a row of long plumose setae. Posterior margin of basis serrate.

Pereopod 7 general appearance similar to pereopod 6. Basis medially with a row of short simple setae.

Oostegites and gills: Gills present on pereopods 2-7. Oostegites unknown.

Pleonites: Pleonites 1-3 dorsally smooth. Epimeral plate 3 weakly produced and rounded posteriorly, serrations absent.

Urosome: Males with urosome not enlarged. Articulation between urosomites 2 and 3 present. Uropod 1 outer ramus with short robust setae on outer and inner margin, inner ramus with robust setae on inner margin. Uropod 2 outer ramus outer margin with robust setae, inner ramus inner margin with robust setae. Uropod 3 peduncle longer than telson, outer ramus 2-articulate. Rami without setae. Telson entire and rounded distally, submarginal setae on apex present.

Females

Unknown.

Distribution

Known only from the type locality.

Remarks

This species can easily be distinguished from all other stegocephalid taxa by the combination of 1) a laterally produced epistome, 2) the weakly differentiated last two pairs of pereopods, 3) entire telson and 4) the bi-articulate outer ramus of the third uropod. The presence of a not gaping and geniculate maxilla 2 and the smooth mandibular incisors indicate unequivocally that the species is a true member of the subfamily Andaniexinae Berge & Vader, 2001. However, it is not possible to assign it unequivocally to any of the genera of the family: its telson, mandibles and maxilliped resemble closely those found in the three genera *Andaniexis* Stebbing, 1906, *Mediterexis* Berge & Vader, 2001 and *Parandaniexis* Schellenberg, 1929. These three genera are also the only genera within the subfamily that do not possess a locking-process on the inner side anteriorly on the fourth coxa (see Berge & Vader 2003b), but the first maxilla and the weakly differentiated last two pairs of

pereopods have close affinities to those found in the genus *Andaniotes* Stebbing, 1897. In addition, the second maxilla, with its slightly elongate outer plate and the arrangements of setae-rows A-D has closest affinities to the subfamily Andaniopsinae Berge & Vader, 2001. Thus, the assignment of this species to *Mediterexis* seems, at best, a temporary decision. However, as the phylogeny of the family and allocation of its species to genera fall outside the scope of this paper, this species is herein placed in *Mediterexis* based on the close affinities to that genus in the maxilliped, mandibles and epistome. This last character (see Fig 4, *Mediterexis mimonectes* (Ruffo, 1975) was used in the phylogenetic analysis (Berge & Vader 2001), but closer examination has revealed that the epistome shows a more complex set of characters than previously assumed (Berge, *in prep.*). As currently only one single specimen of this new species exists, its epistome was not available for SEM examination. However, examination under the light microscope gives reason to suspect that these two congeners possess a very similar epistome; that of *M. mimonectes* is herein illustrated.

Subfamily Stegocephalinae Dana, 1852

Genus *Stegocephalina* Stephensen, 1925

Stegocephalina wolf sp. n. (Figs 5-7)

Holotype

Male 5mm (SAM C6055), Southern Ocean just North of Heard Island (52° 18' S, 73° 45' E), 245 m. col. W. Zeidler, 13.06.1990, "*Aurora Australis*" st. 65. Sample taken from a sponge. Unique.

Etymology

This species is named after the collector, Dr Wolfgang Zeidler, Adelaide.

Diagnosis

Rostrum rudimentary. Antennae subequal, accessory flagellum shorter than antenna 1 flagellum article 1. Epistome laterally produced, epistomal plate present. Mouthparts forming a conical bundle. Mandibular incisors lateral, toothed. Maxilla 2 gaping and geniculate. Labrum elongate. Pereopod 6 basis posteriorly conspicuously expanded. Uropod 3 outer ramus two-articulate. Telson cleft.

Description

Head: Head retractable under pereonite 1. Rostrum rudimentary

Antennae: Accessory flagellum shorter than flagellum article 1, biarticulate. Antenna 2 peduncle article 3 short, about as long as broad. Peduncle article 4 longer than article 5.

Epistome: Epistome laterally produced, long and triangular. Epistomal plate (medial keel) produced

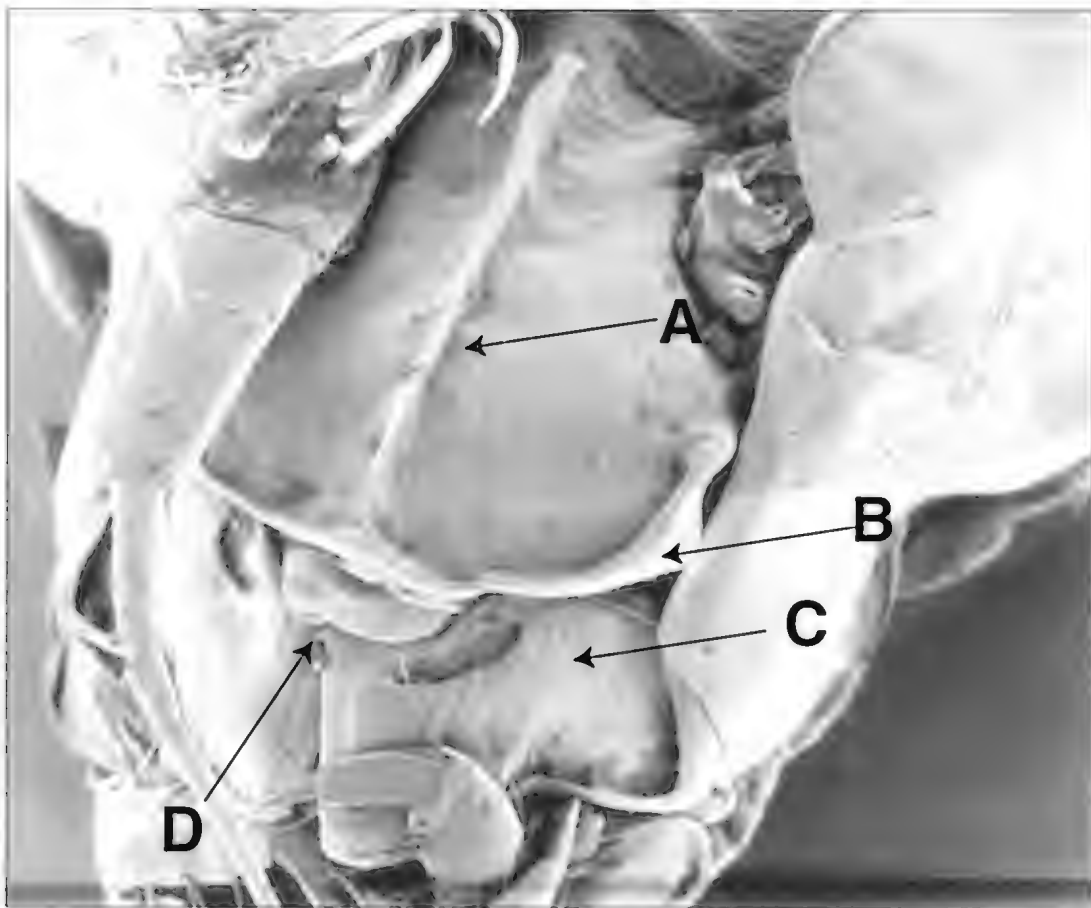


Fig. 4. *Mediterexis mimonectes* Ruffò, 1975. SEM picture of the epistome. A: Epistomal plate, B: Epistome laterally produced, C: Left mandible, D: Labrum.

into a small elongate medial ridge covering the entire epistome.

Mouthparts: Mouthparts elongate.

Mandibles with incisors lateral, toothed. Left lacinia mobilis present, strongly toothed and distally produced.

Maxilla 1 palp articulation absent, distally with short simple setae. Outer plate distally subrectangular, ST in a 6/3 arrangement with two parallel rows: First row with ST 1-5 present, ST 6 absent and ST 7 present. Second row with ST A-C present. Inner plate with shoulder well developed, setae pappopectinate.

Maxilla 2 outer plate gaping and geniculate, setae distally straight. Inner plate with setae-rows A and B appressed together. Rows C and D present.

Maxilliped palp 3-articulate, dactylus absent. Articles 1 and 3 long and weakly setose, article 2 short. Inner plate elongate, 2 nodular setae present. Outer plate with inner and outer setae-row absent.

Distal setae-group present, setae short and simple.

Labrum conspicuously elongate, triangular. Left lobe reduced.

Labium distally narrow, one distal finger present.

Pereopods and coxae: Coxal plates and basis of the pereopods smooth.

Pereopod 1 coxal plate about as deep as basis, basis anterior margin weakly expanded. Pereopod 1 propodus subovate, posteriorly without submarginal row of setae.

Pereopod 2 ischium elongate, distal posterior margin with plumose setae. Propodus subrectangular.

Pereopod 4 coxa locking-structure absent. Basis with long setae on posterior margin, distally with plumose setae on anterior and posterior margins. Ischium with long plumose setae posteriorly.

Pereopod 6 basis posteriorly expanded, medially with a row of long plumose setae. Posterior margin of basis smooth.

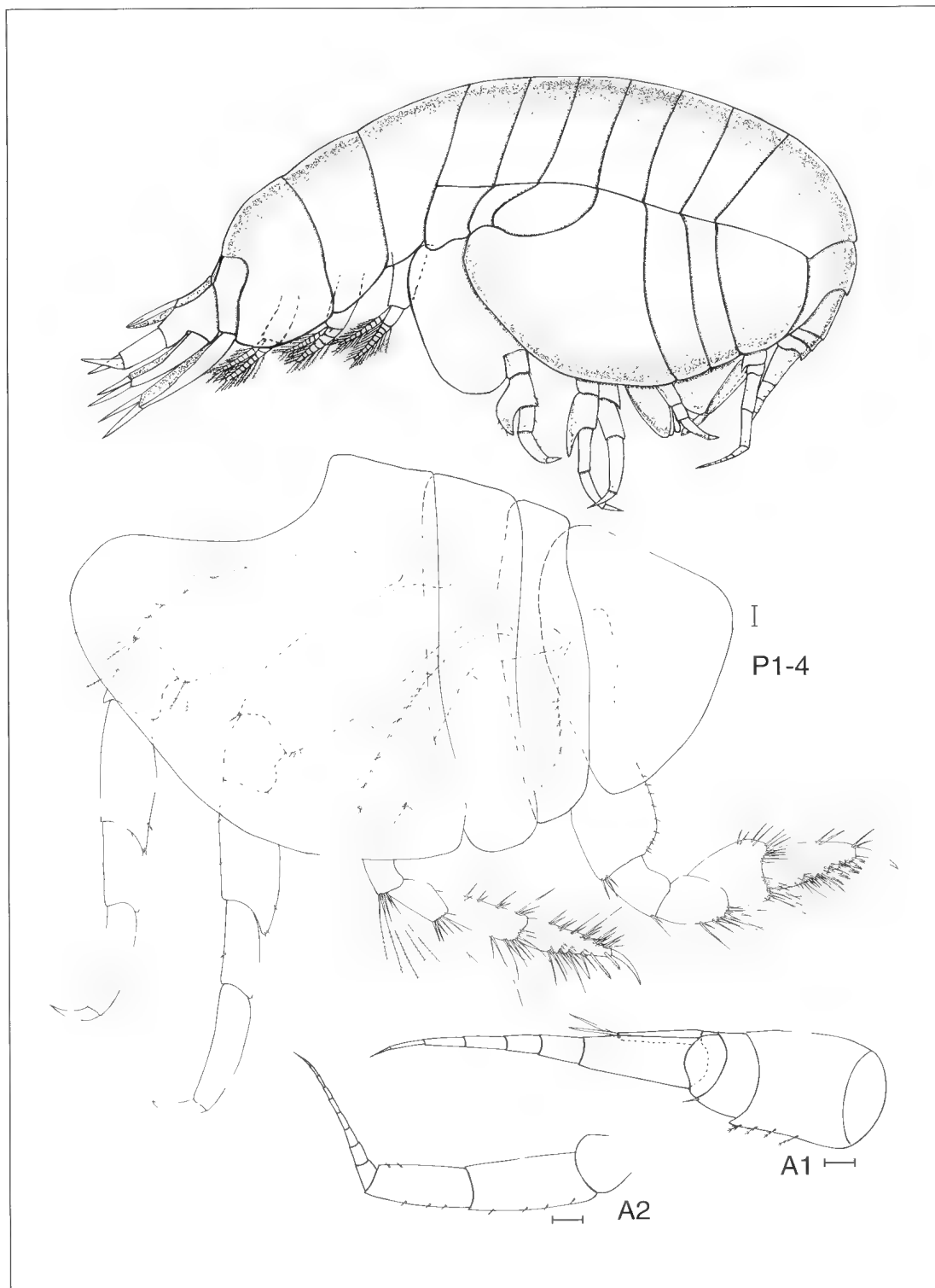


Fig. 5. *Stegocephalina wolf* sp.nov. Holotype.

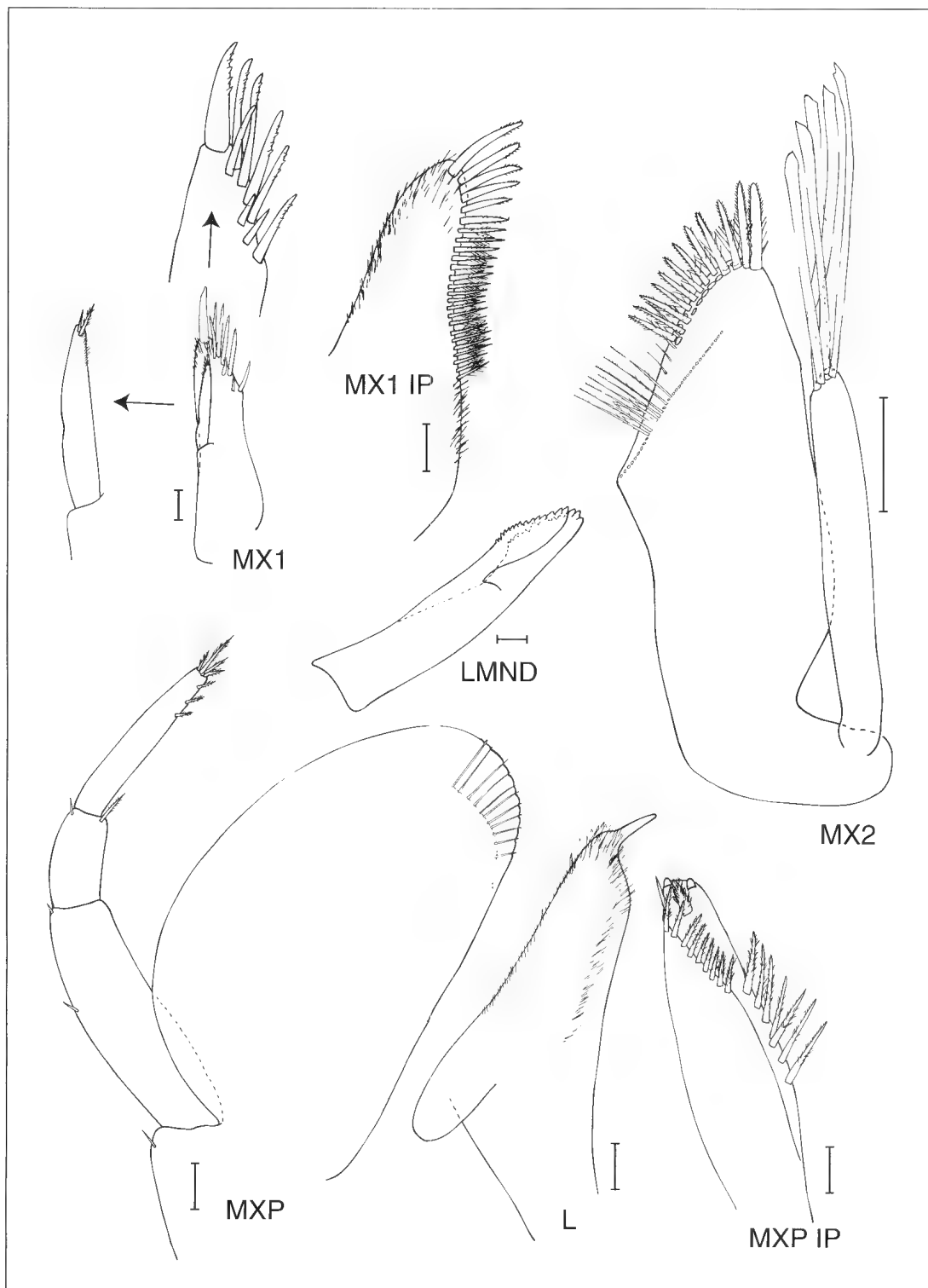


Fig. 6. *Stegocephalina wolf* sp.nov. Holotype.

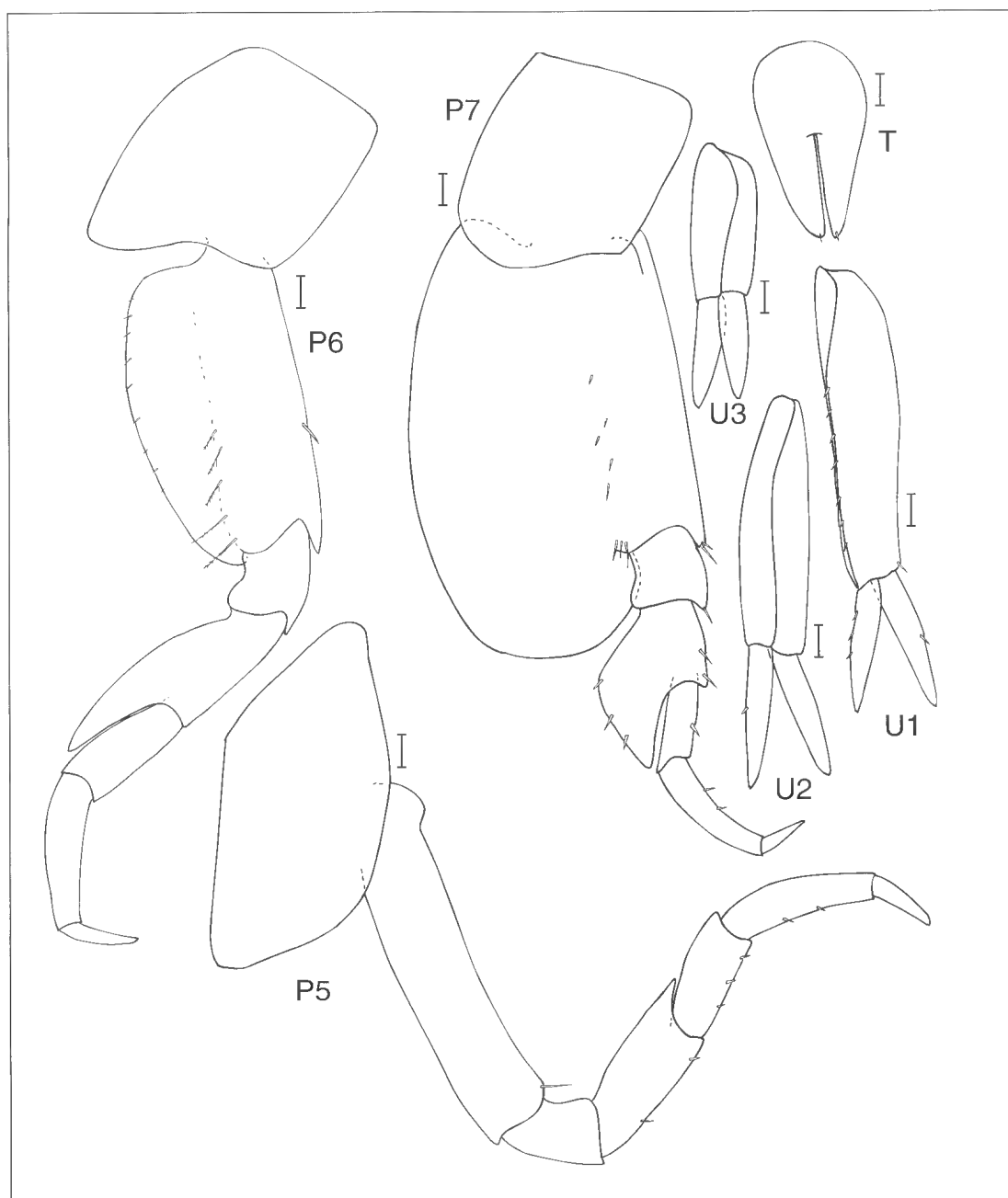


Fig. 7. *Stegocephalina wolf* sp.nov. Holotype.

Pereopod 7 conspicuously different from pereopod 6. Basis posteriorly smooth, medially with a row of short simple setae.

Oostegites and gills: Gills present on pereopods 2-7. Oostegites unknown.

Pleonites: Pleonites 1-3 dorsally smooth. Epimeral plate 3 weakly produced and rounded posteriorly,

serrations absent.

Urosome: Articulation between urosomites 2 and 3 present. Uropod 1 outer ramus with robust setae on outer margin, inner ramus with short robust setae on inner margin. Uropod 2 outer ramus with short robust setae on outer margin. Uropod 3 peduncle not as long as telson, outer ramus 2-articulate.

Telson longer than broad, cleft and rounded distally, submarginal setae on apex present.

Female

Unknown.

Remarks

Stegocephalina wolf is separated from all other stegocephalid species by the combination of 1) the absence of dactylus on the palp of the maxilliped, 2) the fourth article of the peduncle of the second antenna longer than the fifth, and 3) the presence of only one distal finger on the labium.

The present species has close affinities, both phylogenetically and morphologically, to the type species of the genus, *S. ingolfi* Stephensen, 1925. Stephensen (1925:136) wrote that *S. ingolfi* is easily

recognisable e.g. by the long and narrow mouthparts; the same is also true for *S. wolf*. The epistome and mouthparts are in both species conspicuously elongate, projecting well below the coxae. However, the present species differs from *S. ingolfi* in having a considerably shorter article one of the flagellum and only one distal finger on the apex of the labium.

Acknowledgements

We are grateful to Dr Wolfgang Zeidler at the South Australian Museum for providing material. Also, we are indebted to Chris Jones and Prof. Geoff Boxshall at the Natural History Museum in London for their help and support in preparing the SEM pictures.

The first author was funded by the Norwegian Research Council, project number 145384/432.

References

- BERGE, J. (2001) Revision of *Stegosoladidus* Barnard & Karaman, 1987 (Crustacea: Amphipoda: Stegocephalidae); redescription of two species and description of three new species. *Journal of Natural History* **35**, 539-571.
- , DE BROYER, C. & VADER, W. (2000) Revision of the Antarctic and sub-Antarctic species of the family Stegocephalidae (Crustacea: Amphipoda) with description of two new species. *Bulletin de l'Institut des Sciences Naturelles de Belgique* **70**, 217-233.
- & VADER, W. (2001) Revision of the amphipod (Crustacea) family Stegocephalidae. *Zoological Journal of the Linnean Society* **133**, 531-592.
- & — (2003a) Stegocephalid (Crustacea: Amphipoda) species from Australia and New Zealand, with description of seven new species. *Records of the Australian Museum* **55**, 85-112.
- & — (2003b) *Metandania tordi* n.sp. - a new stegocephalid (Crustacea: Peracarida: Amphipoda) species from the Southern Ocean. *Proceedings of the Biological Society of Washington* **116**(4), 1007-1016.
- & — (submitted) Two new Antarctic stegocephalid (Amphipoda: Stegocephalidae: Stegocephalinae) species, with implications for the phylogeny and classification of the two genera *Pseudo* and *Schellenbergia*. *Deep-sea Research Part II*.
- CHILTON, C. (1883) Further additions to our knowledge of the New Zealand Crustacea. *Transactions and Proceedings of the New Zealand Institute* **15**, 69-86.
- DANA, J. D. (1852) Conspectus crustaceorum quae in orbis terrarum circumnavigatione, Carolo Wilkes e classe Reipublicae Faederatae Duce, lexit et descripsit.
- JACOBUS D. DANA. Paris III. *Proceedings of the American Academy of Arts and Sciences* **2**, 201-220.
- HASWELL, W. A. (1879) On Australian Amphipoda. *Proceedings of the Linnean Society of New South Wales* **4**(3), 245-279.
- RUFFO, S. (1975) Nuovi Lisianassidi e Stegocephalidi del Mediterraneo (Crustacea, Amphipoda). *Bollettino del Museo Civico di Storia Naturale di Verona* **1** (1974), 439-453.
- SCELLENBERG, A. (1929) Abyssale und Pelagische Gammariden. *Bulletin of the Museum of Comparative Zoölogy* **LXIX** (9), 193-201.
- STEBBING, T. R. R. (1888) Report of the Amphipoda collected by H.M.S. Challenger during the years 1873-76. *Report on the Scientific Results of the Voyage of H.M.S. Challenger During the Years 1873-76*. Zoology 29: 1737 pp. London: Eyre and Spottiswoode.
- (1897) Amphipoda from the Copenhagen Museum and other sources. *Transactions of the Linnean Society of London Zoology* **7**, 25-45.
- (1906) Amphipoda I. Gammaridea. *Das Tierreich* **21**, 806p.
- SILPHENSEN, K. (1925) Crustacea Malacostraca. VI. (Amphipoda. II.). *The Danish Ingolf-Expedition* **3** (9), 101-178.

**SPECIES OF THE WASP GENUS AULACUS JURINE
(HYMENOPTERA: AULACIDAE) ENDEMIC
TO SOUTH AUSTRALIA**

By J. T. JENNINGS¹, A. D. AUSTIN² & N. B. STEVENS²

Summary

Jennings, J. T., Austin, A. D. & Stevens, N. B. Species of the Wasp genus *Aulacus* Jurine (Hymenoptera: Aulacidae) endemic to South Australia. Trans. R. Soc. S. Aust. 128(1), 13-21, 31 May, 2004.

This study deals with the South Australian species of *Aulacus* Jurine, a fauna that comprises four geographically isolated, endemic species. *Aulacus moerens* Westwood is redescribed, and three new species (*A. belairensis*, *A. flindersbaudini* and *A. grossi*) are recognised. A diagnosis for the genus is presented, along with notes on taxonomic history and species diversity for Australia.

Key Words: Evanioidea, Aulacidae, *Aulacus*, taxonomy, parasitic wasps.

SPECIES OF THE WASP GENUS *AULACUS* JURINE (HYMENOPTERA: AULACIDAE) ENDEMIC TO SOUTH AUSTRALIA.

by J. T. JENNINGS¹, A. D. AUSTIN² & N. B. STEVENS²

Summary

JENNINGS, J. T., AUSTIN, A. D. & STEVENS, N. B. Species of the Wasp genus *Aulacus* Jurine (Hymenoptera: Aulacidae) endemic to South Australia. *Trans. R. Soc. S. Aust.* 128(1), 13–21, 31 May, 2004.

This study deals with the South Australian species of *Aulacus* Jurine, a fauna that comprises four geographically isolated, endemic species. *Aulacus moerens* Westwood is redescribed, and three new species (*A. belairensis*, *A. flindersbaudini* and *A. grossi*) are recognised. A diagnosis for the genus is presented, along with notes on taxonomic history and species diversity for Australia.

KEY WORDS: Evanioidea, Aulacidae, *Aulacus*, taxonomy, parasitic wasps.

Introduction

The Aulacidae are a family of parasitic wasps that are endoparasitoids of wood-boring wasps (Xiphydriidae) and beetles (Cerambycidae and Buprestidae) (e.g. Carlson 1979; Gauld & Bolton 1988; Smith 2001). Although at various times the Aulacidae have been treated as either a subfamily or group of the Evaniidae *s.l.*, most recent studies regard them as a distinct family (e.g. Naumann 1991; Mason 1993; Gauld 1995; Jennings & Austin 2000; Smith 2001).

Like other members of the Evanioidea, aulacids are characterised by the high insertion of the metasoma on the propodeum, but these wasps are also readily distinguished by the presence of fore wing vein 2m-cu (Gauld & Bolton 1988). Worldwide, the Aulacidae comprise 156 valid species (Smith 2001), but this is likely to be only one-third of the true size of the group. Smith (2001) has provided a catalogue of the world fauna, and included 48 species of *Aulacus* Jurine, 106 species of *Pristaulacus* Kieffer, and two species of *Panaulix* Benoit. Both *Aulacus* and *Pristaulacus* are worldwide in their distribution, but *Panaulix* is confined to sub-Saharan Africa. The Australian fauna comprises 34 described species (18 *Aulacus* and 16 *Pristaulacus*) (Smith 2001; Jennings 2001), but most taxa are inadequately described and date from the works of Kieffer (1911; 1912). No taxonomic studies have been undertaken on the Australian fauna since Crosskey (1953) described one *Aulacus* and two *Pristaulacus* species, even though modern collecting techniques, in particular Malaise trapping, have added significantly to the

number of specimens held in collections.

As part of a project that aims to revise the aulacid fauna of Australia, this study deals with the unique and isolated *Aulacus* fauna of South Australia. *Aulacus moerens* Westwood is redescribed, and three new species from the Fleurieu Peninsula, Kangaroo Island, and the far north-west of South Australia are described. At the same time, the genus is redescribed and notes provided on taxonomic history and species diversity.

Materials and Methods

Specimens were observed under a Zeiss light microscope or using scanning electron microscopy (SEM). Specimens for SEM were first cleaned to remove obvious dirt and other debris and examined uncoated under a Phillips XL30 field emission SEM at 1 kv and a spot size of three.

Terms for general morphology follow Jennings and Austin (1994), and for wing venation follow the modified Comstock-Needham system, after Sharkey (1988), but with some modifications, and using the nomenclature of van Achterberg (1979) for cells. Terms for surface sculpturing follow Harris (1979). Where measurements are based on more than one specimen, data are presented as the mean followed by the range. The length of the ovipositor is measured from the tip of the metasoma.

Abbreviations for institutions which are repositories of the specimens referred to in this paper are: Hope Entomological Collections, Oxford (OXUM), South Australian Museum, Adelaide (SAMA), and Waite Insect and Nematode Collection, The University of Adelaide (WINC).

Systematics

Aulacus Jurine, 1807

Aulacus Jurine 1801: 163. [*nom. nud.*]

Aulacus Jurine 1807: 89. Type species: *Aulacus*

Centre for Evolutionary Biology and Biodiversity and School of Agriculture and Wine, The University of Adelaide, Glen Osmond, SA 5064, Australia. Email john.jennings@adelaide.edu.au

² Centre for Evolutionary Biology and Biodiversity, and School of Earth and Environmental Science, The University of Adelaide, SA 5005, Australia.

striatus Jurine 1807, by monotypy (North America and Europe). Blanchard 1840: 300; Schletterer 1889: 489; Kieffer 1903: 383, 453; Bradley 1908: 120; Kieffer 1912: 344, 370; Hedicke 1939: 17; Townes 1950: 113; Townes 1951: 659; Oehlke 1983: 441; Koslov 1988: 243; Alekseev 1995: 39; Konishi 1990: 638; Smith 2001: 268.

Disphaeron Dahlbom 1837: 175. Type species: *Aulacus arcticus* Dahlbom 1837, by monotypy. (syn. Hedicke 1939: 18).

Aulacinus Westwood 1868: 331. Erected as a sub-genus of *Aulacus*. Type species: *Aulacus (Aulacinus) moerens* Westwood 1868, by monotypy. Kieffer 1903: 481; Bradley 1908: 120; Kieffer 1912: 349; Hedicke 1939: 24. (syn. Townes 1950: 113).

Pammegischia Provancher 1882: 302. Type species: *Pammegischia burquei* Provancher 1882, by monotypy. Kieffer 1903: 383; Bradley 1908: 120; Kieffer 1912: 346; Townes 1938: 254; Hedicke 1939: 23. (syn. Kieffer 1902: 11).

Parafoenus Kieffer 1910: 350. No species included. Type species: *Parafoenus formosus* Kieffer 1912, by subsequent monotypy. Kieffer 1912: 345; Hedicke 1939: 26. (syn. Townes 1950: 113).

Neuraulacinus Kieffer 1910: 350. Type species: *Neuraulacinus vespiformis* Kieffer 1910, by subsequent designation, see Kieffer 1912: 358. (designated from three species included by Kieffer 1911). Kieffer 1912: 358; Hedicke 1939: 26. (syn. Townes 1950: 113).

Micraulacinus Kieffer 1910: 350. Type species: *Micraulacinus elegans* Kieffer 1910, by subsequent monotypy, see Kieffer 1912: 348. Kieffer 1912: 348; Hedicke 1939: 24. (syn. Townes 1950: 113).

Disaulacinus Kieffer 1910: 350. Type species: *Disaulacinus flavimanus* Kieffer 1911, by subsequent monotypy, see Kieffer 1911: 224. – Kieffer 1912: 361; Hedicke 1939: 23. (syn. Crosskey 1953: 759).

Pycnaulacus Cushman 1929: 17. Type species: *Pycnaulacus brevicaudus* Cushman 1929, by original designation. (syn. Townes 1950: 113).

Diagnosis based on Australian species

Head with or without occipital carina; frons with or without a transverse carina above antennal sockets; antenna 14-segmented in female, 13-segmented in male; antennal insertions low on face, near lower margin of eyes; eyes small, circular or subcircular, remote from the mandibles; scape usually deeply convex in lateral view, much thicker than pedicel and flagellomeres; metapostnotum present between propodeum and metanotum as a distinct sclerotisation; propodeum pyramidal, metasoma inserted high on the apex; metasomal first tergite (T1) and second tergite (T2) fused dorsally; hind coxa with (Fig. 16) or without a groove or notch on inner ventral surface, the apposed grooves or notches forming an

ovipositor guide; hind trochanter with a transverse trochanteral groove; prefemur (trochantellus) present (Figs 11-12); each tarsal claw with one basal tooth (sometimes difficult to see); fore wings not plicate at rest; fore wing vein 2m-cu present, vein 2r-m often absent, largely spectral when present, vein 3r-m present, often largely spectral (Figs 1, 3, 5); ovipositor exerted, protruding well beyond apex of metasoma.

Comments

Aulacus was first erected as a genus by Jurine (1801), but as a *nomen nudum* since no species were included. In 1807, Jurine rectified this by describing *Aulacus striatus*. Early authors did not define the generic limits of *Aulacus*, so a number of genera were erected (see above) without due consideration of interspecific variation. This resulted in a proliferation of genera: *Disphaeron* Dahlbom, *Disaulacinus* Kieffer, and *Micraulacinus* Kieffer from Australia; *Neuraulacinus* Kieffer from Australia and South America; *Parafoenus* Kieffer from South America; and *Pycnaulacus* Cushman from the USA. By 1912, Kieffer had recognised some 41 species in six genera and the subgenus *Aulacinus* Westwood. Of these, 17 species were Australian. Although Kieffer (1902) had synonymised *Pammegischia* Provancher with *Aulacus*, the mainly North American *Pammegischia* were not transferred to *Aulacus* until much later (Townes 1938). In his 1939 catalogue, Hedicke synonymised *Disphaeron* and included a number of additional species in the other genera. Townes (1950) evaluated various characters such as wing venation, and in the process, defined the generic limits of *Aulacus*. This led him to synonymise *Aulacinus*, *Micraulacinus*, *Neuraulacinus*, *Parafoenus*, and *Pycnaulacus* with *Aulacus*. Townes erroneously synonymised *Disaulacinus* with *Aulacostethus* Philippi (now *Pristaulacus*). *Disaulacinus* was later synonymised with *Aulacus* by Crosskey (1953).

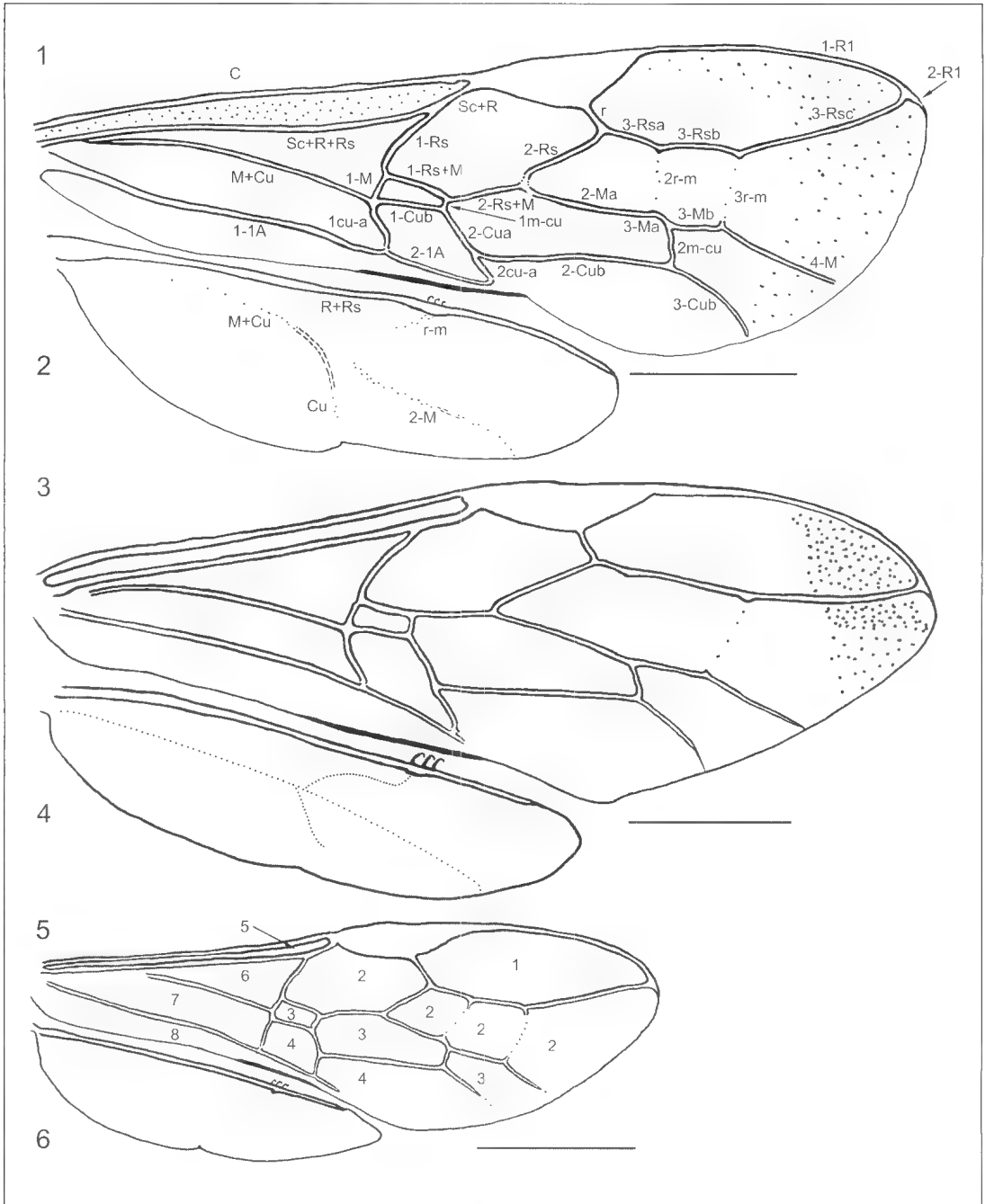
At present, 48 species worldwide are included in *Aulacus*; 18 species are endemic to Australia (Smith 2001; Jennings 2001). Most of the latter are from the higher rainfall, forested areas of the east coast of Australia, including Tasmania. Here we treat the geographically isolated fauna of South Australia and distinguish them from the known Australian taxa. Because there are many undescribed species from south-western and eastern Australia, a key to Australian species would be premature.

Aulacus belairensis sp. nov.
(FIGS 1-2, 7, 11, 13, 16-17, 19)

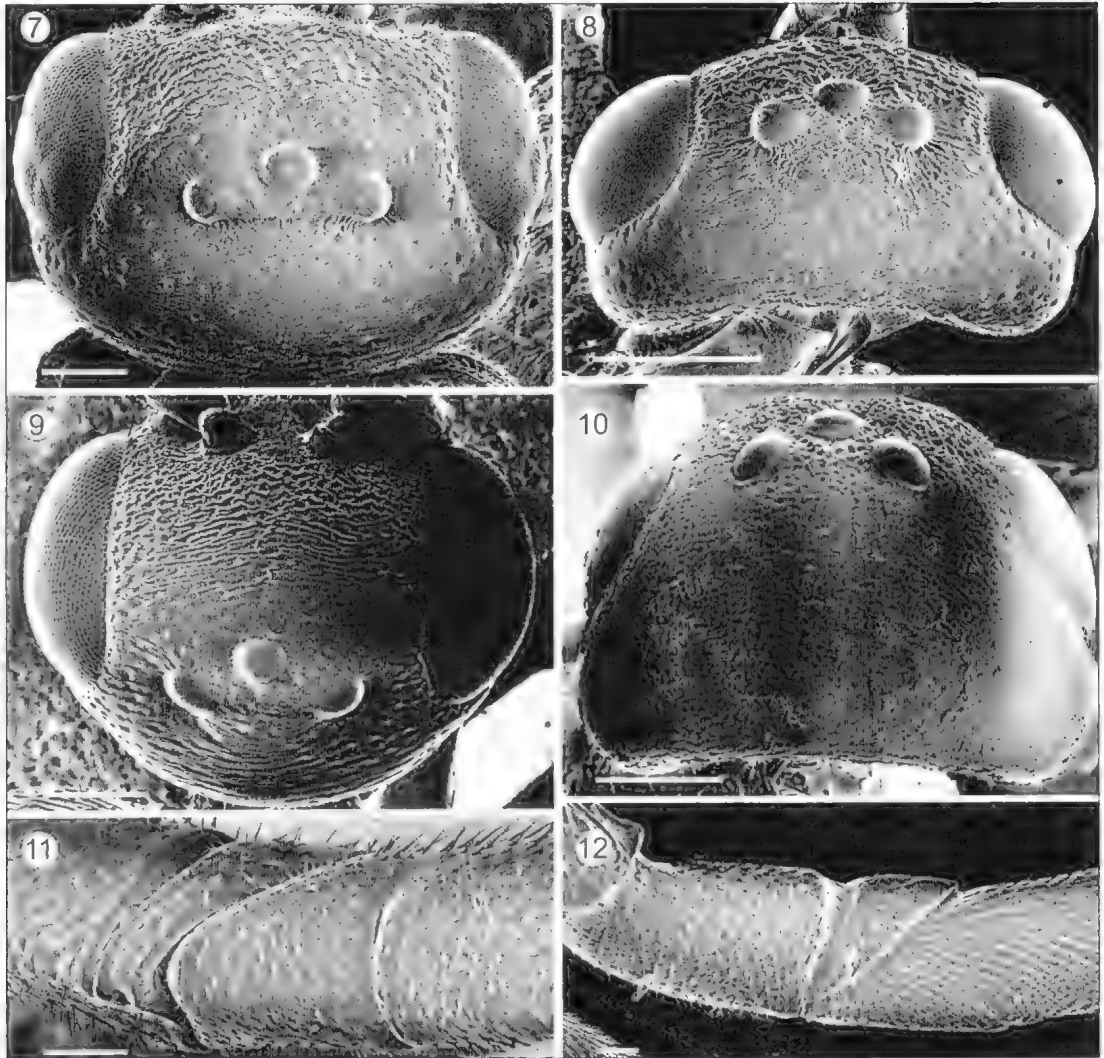
Material Examined

Holotype

♀, Belair N. P., 11-18.ii.1996, J.T. Jennings, SAMA.



Figs 1-6. Fig. 1. Right fore wing of *Aulacus belairensis* sp. nov. holotype female. The cells are: 1 – marginal, 2 – submarginal, 3 – discal, 4 = subdiscal, 5 – costal, 6 – basal, 7 – subbasal, 8 – plical. Fig. 2. Right hind wing of *Aulacus belairensis* sp. nov. holotype female. Fig. 3. Right fore wing of *Aulacus flindersbaudini* sp. nov. holotype male. Fig. 4. Right hind wing of *Aulacus flindersbaudini* sp. nov. holotype male. Fig. 5. Right fore wing of *Aulacus grossi* sp. nov. holotype female. Fig. 6. Right hind wing of *Aulacus grossi* sp. nov. holotype female. Scale bars – 1 mm.



Figs 7-12. Dorsal views of head. Fig. 7. *Aulacus belairensis* sp. nov. holotype female. Fig. 8. *Aulacus flindersbaudini* sp. nov. holotype male. Fig. 9. *Aulacus grossi* sp. nov. holotype female. Fig. 10. *Aulacus moerens* holotype female. Lateral views of hind trochanter and prefemur. Fig. 11. *Aulacus belairensis* sp. nov. holotype female. Fig. 12. *Aulacus flindersbaudini* sp. nov. holotype male. Scale bars = 200 µm 7, 9; 500 µm 8, 10; 50 µm 11, 12

Paratypes

SA: 1 ♀, Belair National Park, 10-17.iii.1996, J.T. Jennings, WINC; 1 ♀, Belair National Park, xii.1996, J.T. Jennings, WINC.

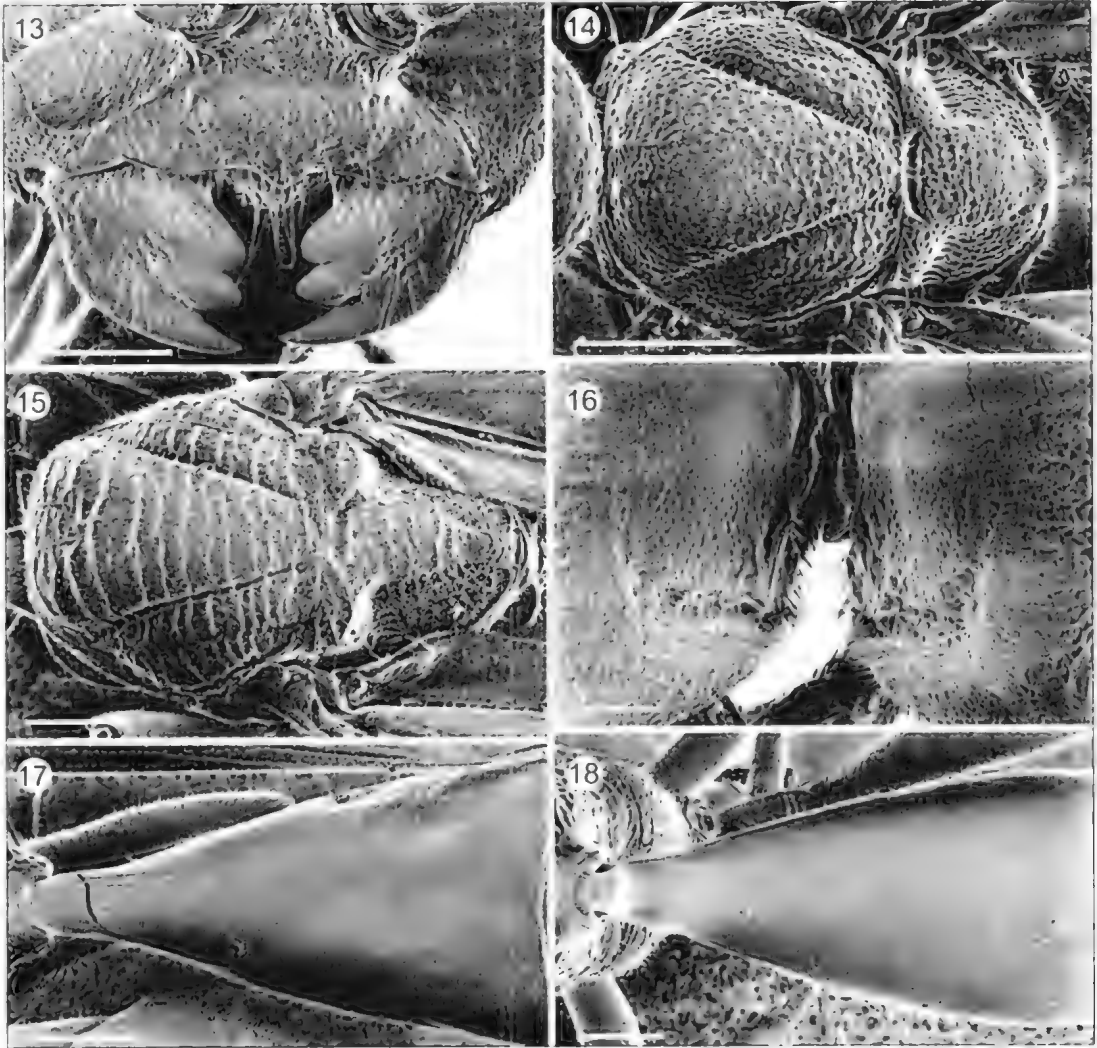
Female

Length: 5.0 mm (4.4–5.5 mm), excluding ovipositor.

Colour: Head orange, with variable amounts of dark brown around ocelli; scape and pedicel orange with flagellomeres dark brown; propleuron dark

brown; body black except for variable amounts of orange on pronotum; legs predominantly light to dark brown; metasoma dark brown; ovipositor sheaths black, ovipositor orange; wings fuscous, darker apically on the marginal and submarginal cells.

Head: 1.2 (1.0–1.3) x wider than long when viewed dorsally; face rugose, with a few large punctures near eye margin, pubescence short; frons without transverse carina above toruli, rugose, with a few punctures near eye margin, pubescence short;



Figs 13-18. Fig. 13. Mandibles and clypeus of *Aulacus belairensis* sp. nov. holotype female. Fig. 14. Dorsal view of mesoscutum, scutellum and axillae of *Aulacus belairensis* sp. nov. holotype female. Fig. 15. Dorsal view of mesoscutum, scutellum and axillae of *Aulacus flindersbaudini* sp. nov. holotype male. Fig. 16. Ovipositor guide on hind coxae of *Aulacus belairensis* sp. nov. holotype female. Fig. 17. Dorsal view of metasomal T1 and T2 of *Aulacus belairensis* sp. nov. holotype female. Fig. 18. Dorsal view of metasomal T1 and T2 of *Aulacus grossi* sp. nov. holotype female. Scale bars = 200 μ m 13, 17, 18; 500 μ m 14, 15; 100 μ m 16.

vertex and gena punctate-imbricate, a few radiating striations near ocelli, with scattered short setae (Fig 7); posterior margin of head not concave in dorsal view; malar space 0.25 x height eye; clypeus 0.37 x as wide as high, margin sinuate with small medial process (Fig. 13); mandibles broad, with two large medial teeth (Fig. 13); distance from lateral ocellus to eye margin 0.83 (0.78 – 0.90) x distance between lateral ocelli; scape 1.6 (1.6 – 1.7) x length pedicel; first flagellomere 1.0 (0.9 – 1.1) x as long as scape,

equal to length second flagellomere.

Mesosoma. Propleuron rugulose, pubescence long, ventro-lateral carina weak; pronotum rugose; mesoscutum in lateral view rounded antero-dorsally, medial and lateral lobes rugose-punctate, with scattered setae, admedial lines present (Fig. 14); scutellum and axillae rugose-punctate (Fig. 14); mesepisternum reticulate, with short pubescence; mesepimeron broad, scrobiculate; metapleuron rugose, with short pubescence; propodeum rugose,

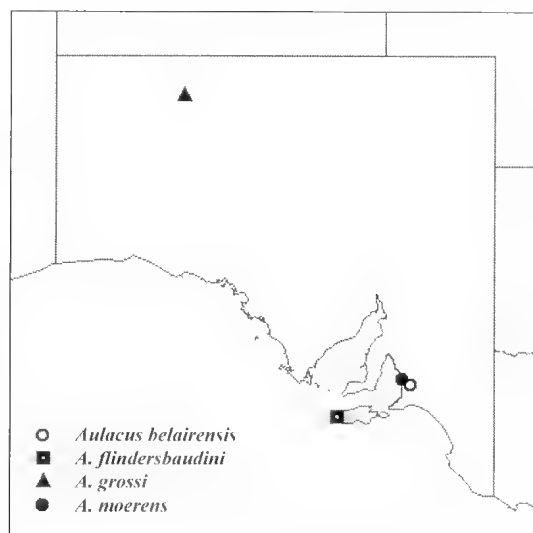


Fig. 19. Distribution of South Australian *Aulacus* spp.

posterior margin scrobiculate; hind coxa with ovipositor guide ventrally on inner margin (Fig. 16); hind trochanter and femur imbricate, pubescence short; prefemur somewhat indistinct (Fig 11); hind tibia imbricate, pubescence short, with scattered emergent stout setae; hind femur 0.70 ($0.68 - 0.72$) \times length hind tibia; hind tibia with ventro-apical pecten of short robust spines; hind tarsal segments 1-4 with ventro-apical pecten of short robust spines, segment 1, $2.8 \times$ length segment 2; segment 2, $1.4 \times$ length segment 3; segment 3, $1.6 \times$ length segment 4; segment 4, $0.6 \times$ length segment 5; hind tarsal claw $0.5 \times$ length segment 5; fore wing vein 2r-m and 3r-m largely spectral (Fig. 1); hind wing with 3 hamuli (Fig. 2).

Metasoma. Clavate, 1.67 ($1.54 - 1.71$) \times length of mesosoma; T1 and T2 anteriorly narrow, smooth dorsally except for a few strigate wrinkles anteriorly on T1; ovipositor 5.9 ($5.0 - 6.5$) mm.

Male

Unknown.

Remarks

This species is named after the holotype locality, Belair National Park, South Australia (Fig. 19). All specimens were collected by Malaise trap, and nothing is known of its biology. This species can be separated from other South Australian species by the fuscous wings that are darker apically on the marginal and submarginal cells, and the strigate wrinkles anteriorly on metasomal T1. Also, it is similar in size and appearance to *A. elegans* (Kieffer) which has been collected from several localities in New South Wales and Victoria. The two can be

easily separated in that *A. elegans* has a shiny head, an orange metasoma, and has different sculpturing patterns; for example, the vertex is largely smooth with just a few scattered shallow punctures.

Aulacus flindersbaudini sp. nov.
(FIGS 3-4, 8, 12, 15, 19)

Material Examined

Holotype

♂, West Bay, Flinders Chase Nat. Park, Kangaroo Is. S.A., i.1986, A.D. Austin, SAMA. [Flagellomeres 2-11, right hind tarsal segments 4-5, and claw missing].

Male

Length: 8.0 mm.

Colour: Body red except metasomal T1 dark brown dorsally; flagellomeres 2 and 3 black; wings hyaline; fore wing with brown spot apically on the marginal and submarginal cells.

Head: $1.6 \times$ wider than long when viewed dorsally; face punctate-imbricate, pubescence short; frons without transverse carina above toruli, areolate-rugose, pubescence short; vertex areolate-rugose medially, with a few radiating striations near ocelli, with a few transverse striations posteriorly, punctate-imbricate laterally, pubescence short (Fig. 8); gena punctate-imbricate, with scattered short setae; posterior margin of head slightly concave in dorsal view; malar space $0.34 \times$ height eye; clypeus $3.7 \times$ as wide as high, margin sinuate with small medial process; mandibles broad, with two large medial teeth; distance from lateral ocellus to eye margin equal to distance between lateral ocelli; scape $1.8 \times$ length pedicel; length first flagellomere equal to length scape, second flagellomere missing.

Mesosoma. Propleuron smooth anteriorly to weakly rugulose posteriorly, with scattered long setae; ventro-lateral carina weak; pronotum rugulose; mesoscutum in lateral view rounded antero-dorsally, medial and lateral lobes strigate with scattered short setae, admedial lines present (Fig. 15); scutellum and axillae strigate (Fig. 15); mesepisternum areolate-rugose, with short pubescence; mesepimeron broad, scrobiculate; metapleuron areolate-rugose, with short pubescence; propodeum areolate-rugose, posterior margin scrobiculate; hind coxa without groove ventrally on inner margin, weakly rugulose to strigate dorsally, pubescence short laterally; hind trochanter imbricate, pubescence short; prefemur indistinct (Fig 12); hind femur imbricate, pubescence short; hind tibia imbricate, pubescence short, with scattered emergent stout setae; hind femur $0.77 \times$ length hind tibia; hind tibia with ventro-apical pecten of short robust spines; hind tarsal segments 1-4 with ventro-apical pecten of

short robust spines, segment 1, 2.0 x length segment 2; segment 2, 1.6 x length segment 3; segment 3, 2.4 x length segment 4; segment 4, 0.8 x length segment 5; hind tarsal claw 0.7 x length segment 5; fore wing vein 2r-m incomplete, evident only by a small node on 2r, 3r-m entirely spectral (Fig. 3); hind wing with 2 hamuli (Fig. 4).

Metasoma. Clavate, 1.5 x length of mesosoma; T1 and T2 dorsally narrow, smooth; digitus about same length as basiparameres.

Female

Unknown.

Remarks

Aulacus flindersbaudini is named to commemorate the meeting of Matthew Flinders and Nicolas Baudin at Encounter Bay, South Australia in 1802. This species is known only from the holotype location (Fig. 19), and nothing is known of its biology. This species is readily distinguished from other South Australian species by the presence of a brown spot apically on the marginal and submarginal cells of the fore wing (Fig. 3); this spot is absent in the other species. *Aulacus flindersbaudini* also lacks the groove or ovipositor guide on the inner margin of the hind coxae. The brown spot on the fore wing is found in several species from south-western and eastern Australia, such as *A. pallicaudus* (Cameron), but all of these species are largely black.

Aulacus grossi sp. nov.
(FIGS 5-6, 9, 18-19)

Material Examined

Holotype

♀, nr. Victory Well, Everard Pk Stn, S. Aust. 2-4.xi.1970. G. Gross, SAMA.

Female

Length: 4.5 mm, excluding ovipositor.

Colour: Head black; mesosoma, antennae, and legs light brown; metasoma black except for basal part of metasomal T1; wings hyaline.

Head: 1.1 x wider than long when viewed dorsally; face, frons without transverse carina above toruli; frons and vertex rugose-punctate (Fig. 9), with scattered short setae, a little denser on face; gena smooth, almost glabrous; posterior margin of head not concave in dorsal view; malar space 0.16 x height eye; clypeus 4.0 x as wide as high, punctate, margin sinuate with small medial process; mandibles broad, with two large medial teeth; distance from lateral ocellus to eye margin 0.72 x distance between lateral ocelli; scape 1.8 x length pedicel; first flagellomere 0.72 x as long as scape, 0.52 x as long as second flagellomere.

Mesosoma. Propleuron weakly rugulose-punctate, almost smooth, with a few scattered setae; ventro-lateral carina weak; pronotum rugose-punctate; mesoscutum in lateral view rounded antero-dorsally, medial and lateral lobes rugose, almost strigate, with scattered short setae, admedial lines distinct; scutellum and axillae rugose, almost strigate; mesepisternum rugose-punctate, with short pubescence; mesepimeron broad, scrobiculate; metapleuron rugose-punctate, with short pubescence; propodeum rugose, with several pronounced carinae, posterior margin scrobiculate; hind coxa with groove ventrally on inner margin, weakly strigate dorsally, pubescence short; hind trochanter and hind femur imbricate, pubescence short; hind tibia imbricate, pubescence short, with scattered emergent stout setae; hind femur 0.8 x length hind tibia; hind tibia with ventro-apical pecten of short robust spines; hind tarsal segments 1-4 with ventro-apical pecten of short robust spines, segment 1, 2.9 x length segment 2; segment 2, 1.35 x length segment 3; segment 3, 2.0 x length segment 4; segment 4, 0.5 x length segment 5; hind tarsal claw 0.5 x length segment 5; fore wing veins 2r-m and 3r-m largely spectral (Fig. 5); hind wing with 2 hamuli (Fig. 6).

Metasoma. Clavate, equal in length to mesosoma; T1 and T2 dorsally broad, smooth (Fig. 18); ovipositor 4.2 mm.

Male

Unknown.

Remarks

Aulacus grossi has a broad metasoma when viewed dorsally which distinguishes it from both *A. belairensis* and *A. flindersbaudini*. It is also the smallest Australian species of *Aulacus* known, and can be distinguished from all other Australian species by its colour pattern, i.e. head and metasoma black, and mesosoma light brown. *Aulacus grossi* is known from a single specimen from Everard Park Station in the north-west of South Australia (Fig. 19), and is named after the collector, Dr Gordon Gross, formerly Curator of Entomology, South Australian Museum. Nothing is known about its biology.

Aulacus moerens Westwood
(FIGS 10, 19)

Aulacus (Aulacinus) moerens Westwood 1868: 331. – Westwood 1874: 129; Schletterer 1889: 517.

Aulacinus moerens Kieffer 1902: 12; Kieffer 1903: 481; Kieffer 1904: 6; Kieffer 1912: 349, 356; Hedicke 1939: 25.

Aulacus maerens – Dalla Torre 1902: 1061 (unnecessary emendation)

Aulacus moerens – Smith 2001: 273.

*Material Examined**Holotype*

♀, Adelaide [illeg.] 1865, OXUM. Antennae missing, head glued to mesosoma, metasoma glued to card, ovipositor sheaths missing.

Female

Length: 10.5 mm, excluding ovipositor.

Colour: Black, except tibiae and tarsi largely light brown, ovipositor light brown; wings hyaline.

Head: 1.18 wider than long when viewed dorsally; face rugulose, pubescence long; frons with pronounced transverse carina above toruli, rugulose, with long pubescence; vertex punctulate-imbricate, slight rugosity posteriorly near occiput, with short scattered setae (Fig. 10); gena punctulate-imbricate, with scattered short setae; posterior margin of head not concave in dorsal view; malar space 0.2 x height eye; clypeus 4.0 x as wide as high, margin sinuate; mandibles broad, with two large medial teeth; distance from lateral ocellus to eye margin 0.9 x distance between lateral ocelli; antennae missing.

Mesosoma. Propleuron rugulose, pubescence long, ventro-lateral carina present; pronotum without angular process, rugose; mesoscutum in lateral view angular antero-dorsally, medial and lateral lobes strigate, with scattered short setae, admedial lines present; scutellum strigate; axillae rugose; mesepisternum rugose, with long pubescence; mesepimeron broad, scrobiculate; metapleuron rugose, with short pubescence; propodeum rugose, with medial dorso-ventral scrobiculate groove, posterior margin scrobiculate; hind coxa without groove ventrally on inner margin, strigate dorsally, pubescence long laterally; hind trochanter punctulate-imbricate, pubescence short; hind femur imbricate, pubescence short; hind tibia imbricate,

pubescence short, with scattered emergent stout setae; hind femur 0.74 x length hind tibia; hind tibia without ventro-apical pecten of short robust spines; hind tarsal segments 1-4 with ventro-apical pecten of short robust spines, segment 1, 2.7 x length segment 2; segment 2, 1.6 x length segment 3; segment 3, 2.0 x length segment 4; segment 4, 0.4 x length segment 5; hind tarsal claw 0.6 x length segment 5; fore wing vein 2r-m pale brown, tubular, 3r-m spectral in middle half; hind wing with 3 hamuli.

Metasoma. Ovate, 1.25 x length of mesosoma; T1 and T2 smooth except slight rugosity medially; ovipositor 4.0 mm.

Male

Unknown.

Remarks

Although both *A. grossi* and *A. moerens* have an ovate metasoma, the latter species is a much larger and differs in a number of ways, including its largely black colour, the lack of an ovipositor guide on the hind coxae, and the presence of a small medial process on the clypeus. It does not resemble any other Australian species. This species is known only from the holotype locality, Adelaide, South Australia (Fig. 19), and nothing is known of its biology.

Acknowledgments

We thank the curators of the collections listed above for the loan of specimens, and the staff of Adelaide Microscopy, The University of Adelaide, for access to the FESEM. This work was carried out with the assistance of an Australian Biological Resources Study grant and a Small ARC grant to J TJ and ADA.

References

- ALFESLEV, V. N. (1995) Evanioidea pp. 37-45 *In* Lehr, P.A. (Ed.) ["Keys to Insects of Russian Far East in Six Volumes". Vol. IV. Neuropteroidea, Mecoptera, Hymenoptera. Part 2. Hymenoptera] (Dal'nauka, Vladivostok) [in Russian].
- BLANCHARD, E. (1840) "Histoire Naturelle des Animaux Articulés, Annelides, Crustacés, Arachnides, Myriapodes et Insectes", Vol. 3. (Paris).
- BRADLEY, J. C. (1908) The Evaniidae, ensign-flies, an archaic family of Hymenoptera. *Trans. Am. ent. Soc.* **34**, 101-194, plates V-XV.
- CARLSON, R. W. (1979) Aulacidae pp. 1111-1115 *In* Krombein, K.V., P.D. Hurd, Jr., D.R. Smith & B.D. Burks (Eds.) "Catalog of Hymenoptera in America North of Mexico". Volume 1. (Smithsonian Institution Press, Washington, D.C.).
- CROSSKEY, R. W. (1953) Two new species of *Aulacostethus* Philippi and a new species of *Aulacus* Jurine, from Australia, together with a key to the Australian species of *Aulacostethus* (Hymenoptera: Aulacidae). *Ann. Mag. nat. Hist.* (12) **6**, 758-766.
- CUSHMAN, R. A. (1929) New species of ichneumon-flies and taxonomic notes. *Proc. U. S. natn. Mus.* **76**, 1-18.
- DAHLBOM, G. (1837) Species Aulaci Generis in Scandinavia habitantes. *Isis. Jena* **3**, 173-177.
- DALLA TORRE, C. G. de (1902) "Catalogus Hymenopterorum hucusque descriptorum systematicus et synonymicus", Volumen III: Trigonalidae, Megalyridae, Stephanidae, Ichneumonidae, Agriotypidae, Evaniidae, Pelecinidae. Pars II., pp. 545-1141. (Lipsiae).

- GAULD, I. D. (1995) Aulacidae pp. 192-193 *In* Hanson, P.E. & I.D. Gauld (Eds.) "The Hymenoptera of Costa Rica" (Oxford University Press, Oxford).
- & BOLTON, B. (Eds.) (1988) "The Hymenoptera". (Oxford University Press, Oxford).
- HARRIS, R. A. (1979) A glossary of surface sculpturing. *Calif. Dept. Food Agric., Bureau Entomol., Occ. Papers* **28**, 1-28.
- HEDICKE, H. (1939) Aulacidae *In* Hedicke H. (Ed.) "Hymenopterorum Catalogus", Pars 10. (Dr. W. Junk, Gravenhage).
- JENNINGS, J. T. (2001) Aulacidae. [Checklist of Australian species] Australian Faunal Directory, Australian Biodiversity Information Facility, Environment Australia. (<http://www.environment.gov.au/abrs/online/resources/abif-fauna>).
- & AUSTIN, A. D. (1994) Revision of the genus *Crassifoenus* Crosskey (Hymenoptera: Gasteruptionidae: Hyptiogastrinae), with a description of a new species from Western Australia. *Rec. West. Aust. Mus.* **16**, 575-591.
- & _____ (2000) Higher-level phylogeny of the Aulacidae and Gasteruptionidae (Hymenoptera: Evaniidae) pp. 154-164 *In* Austin, A.D. & M. Dowton (Eds.) "Hymenoptera. Evolution, Biodiversity and Biological Control". (CSIRO Publishing, Collingwood).
- JURINE, L. (1801) Nachricht von einem Neuen Entomologischen Werks, des Hrn. Prof. Jurine in Geneve. *Intellig. Litt.-Z., Erlangen* **1**, 161-165.
- (1807) "Nouvelle Méthode de Classer les Hyménoptères et les Diptères. Hyménoptères". Tome Premier. (Geneve), 319 pp.
- KIEFFER, J. -J. (1902) Hymenoptera, Fam. Evaniidae *In* Wytman, P. (Ed.) "Genera Insectorum", Fascicule 2, 13 pp., 1 plate. (Bruxelles).
- (1903) Les Evaniidae pp. 347-482 *In* André, E. "Species des Hyménoptères d'Europe & d'Algérie". Volume 7, part 2 (Paris).
- (1904) Description de Stéphanides et d'évaniides nouveaux. *Bull. Soc. Hist. Nat. Metz* **11**, 1-30.
- (1910) Diagnoses de nouveaux genres d'Aulacinae (Hym.). *Bull. Soc. ent. Fr.* **1910**, 350.
- (1911) Etude sur les Evaniides exotiques (Hym.) du British Muscum de Londres. *Ann. Soc. ent. Fr.* **80**, 151-231.
- (1912) Hymenoptera, Ichneumonidae, Evaniidae. *Das Tierreich*, **30**, 1-431.
- KONISHI, K. (1990) A revision of the Aulacidae of Japan (Hymenoptera, Evanioidea). *Jap. J. Ent.* **58**, 637-655.
- KOSLOV, M. A. (1988) Aulacidae pp. 242-244 *In* Medvedev, G.S. (Ed.) ["Keys to the Insects of the European Part of the USSR"], Vol. III, Hymenoptera, Part VI Symphyta. Akademia Nauk SSSR, Zoologicheskii Institut 267 pp. [Translation, 1994, E.J. Brill, Leiden].
- MASON, W. R. M. (1993) Chapter 11. Superfamilies Evanioidea, Stephanoidea, Megalyroidea, and Trigonalyoidea pp. 510-520 *In* Goulet, H. & J.T. Huber (Eds.) "Hymenoptera of the World: An Identification Guide to Families". (Research Branch, Agriculture Canada).
- NAUMANN, I. D. (1991) Chapter 42. Hymenoptera (Wasps, bees, ants, sawflies) pp. 916-1000 *In* Naumann, I. D. (Ed.) "The Insects of Australia, A Textbook for Students and Research Workers". Volume II. (Melbourne University Press).
- ORHILKE, J. (1983) Revision der europäischen Aulacidae (Hymenoptera Evanioidea). *Beitr. Ent.*, **33**, 439-447.
- PROVANCHER, A. L. (1882) Faune Canadienne, Hyménoptères, Additions et Corrections. *Naturaliste can.* **13**, 289-311.
- SCHLITTFER, A. (1889) "Die Hymenopteren-Gruppe der Evaniiden". III. Abteilung. *Anal. des K. K. Naturhistorischen Hofmuseums, Separatabdruck aus band IV* pp. 373-546.
- SHARKEY, M. (1988) Ichneumonoid wing venation. *Ichneumon* **11**, 2-12.
- SMITH, D. R. (2001) World catalog of the family Aulacidae (Hymenoptera). *Contrib. Ent., Int.* **4**, 263-319.
- TOWNES, H. K. (1938) *Pammegischia* and *Trichofoenus* discarded (aulacoid Hymenoptera). *Can. Ent.* **70**, 254-255.
- (1950) The Nearctic species of Gasteruptionidae (Hymenoptera). *Proc. U. S. natn. Mus.* **100**, 85-145.
- (1951) Aulacinae pp. 657-660 *In* Muesebeck, C. F. W., K. V. Krombein, & H. K. Townes (Eds.) "Hymenoptera of America North of Mexico, Synoptic Catalog." (United States Department of Agriculture) Agriculture Monograph No. 2.
- VAN ACHTERBERG, C. (1979) A revision of the Subfamily Zelinae auct. (Hymenoptera, Braconidae). *Tijdschr. Ent.* **122**, 241-479.
- WESTWOOD, J. O. (1868) XVIII. Descriptions of new genera and species of exotic Hymenoptera. *Trans. ent. Soc. Lond.* **1868**, 327-332.
- (1874) "Thesaurus Entomologicus Oxoniensis; or, illustrations of new, rare, and interesting insects, for the most part contained in the collections presented to the University of Oxford by the Rev. F. W. Hope, M. A., D. C. L., F. R. S. &c, with forty plates from drawings by the author" (Oxford).

THE REPRODUCTIVE ECOLOGY OF TWO NATURALISED ERICA SPECIES (ERICACEAE) IN THE ADELAIDE HILLS: THE RISE AND FALL OF TWO ‘WOULD-BE’ WEEDS?

By D. TURNER^{1,2} & J. G. CONRAN^{1,3}

Summary

Turner, D. & Conran, J. G. (2004). The reproductive ecology of two naturalised *Erica* species (Ericaceae) in the Adelaide Hills: the rise and fall of two ‘would-be’ weeds? *Trans. R. Soc. S. Aust.* 128(1), 23-31, 31 May, 2004.

The pollination biology and reproductive ecology of the newly naturalised species *Erica cinerea* from Europe and *E. glandulosa* from South Africa (Ericaceae) are reported from the Adelaide Hills from surveys undertaken in 1995 and 2003. Examination of UV floral reflectance, nectar composition and floral visitors found that *E. cinerea* was honeybee pollinated (although the bees also practiced nectar theft by chewing through the corolla tube), whereas *E. glandulosa* was probably pollinated by New Holland Honeyeaters (*Phylidonyris novaehollandiae*: Meliphagidae) which filled the niche of the nectariniid Sunbirds which pollinate it in South Africa.

Key Words: *Erica*, *E. cinerea*, *E. glandulosa*, Ericaceae, weed biology, reproductive ecology, pollination, fecundity, Australia.

THE REPRODUCTIVE ECOLOGY OF TWO NATURALISED *ERICA* SPECIES (ERICACEAE) IN THE ADELAIDE HILLS: THE RISE AND FALL OF TWO ‘WOULD-BE’ WEEDS?

by D. TURNER^{1,2} & J. G. CONRAN^{1,3}

Summary

TURNER, D. & CONRAN, J. G. (2004). The reproductive ecology of two naturalised *Erica* species (Ericaceae) in the Adelaide Hills: the rise and fall of two ‘would-be’ weeds? *Trans. R. Soc. S. Aust.* 128(1), 23–31, 31 May, 2004.

The pollination biology and reproductive ecology of the newly naturalised species *Erica cinerea* from Europe and *E. glandulosa* from South Africa (Ericaceae) are reported from the Adelaide Hills from surveys undertaken in 1995 and 2003. Examination of UV floral reflectance, nectar composition and floral visitors found that *E. cinerea* was honeybee pollinated (although the bees also practiced nectar theft by chewing through the corolla tube), whereas *E. glandulosa* was probably pollinated by New Holland Honeyeaters (*Phylidonyris novaehollandiae*: Meliphagidae) which filled the niche of the nectariniid Sunbirds which pollinate it in South Africa. Although fecundity data in 1995 suggested that there was considerable capacity for these plants to become weeds, the 2003 survey found that they had declined significantly, apparently as a result of competition or shading from taller, more aggressive weeds, mainly Bracken (*Pteridium esculentum*) and Tree Erica (*E. arborea*). Nevertheless, as *E. cinerea* reseeds and *E. glandulosa* resprouts after fire, and *E. cinerea* can persist in the soil seed bank for over 30 years, their populations may recover and/or expand if the area where they are growing is opened up by fire.

KEY WORDS: *Erica*, *E. cinerea*, *E. glandulosa*, Ericaceae, weed biology, reproductive ecology, pollination, fecundity, Australia.

Introduction

Erica L. is a large genus of heaths which is centred around South Africa (Guthrie & Bolus 1905; Baker & Oliver 1967), with a second radiation in southern and western Europe (Webb & Rix 1972). Much of Southern Africa and Mediterranean Europe is characterised by cool winters and hot dry summers similar to South Australia and most members of the genus grow in nutrient poor, acidic soils. The European species, in particular, tend to be mycorrhizal, and the majority are calcifuges (Gimingham *et al.* 1979; Webb 1986). In many respects the soils of the South African Cape, Mediterranean Europe and South Australia are similar in being nutrient poor, often acidic, and support conspicuous sclerophyllous heath elements, represented in South Africa and Europe by the Ericaceae and in Australia by Epacridaceae (Specht 1979, 1981).

There are three *Erica* spp. listed as naturalised in South Australia (Jessop & Toelken 1986): the European *E. arborea* L. and *E. lusitanica* Rudolphi, and the South African *E. baccans* L. Of these, the two European species, and *E. arborea* in particular,

are widespread weeds on nutrient-poor, acidic soils with moderate to high rainfall (Cshures & Edwards 1998; Ojeda 1998). *Erica* spp. tend to coincide growth with water availability during winter and early spring (Gehrig 2000), flowering from late winter into spring and summer (Jessop & Toelken 1986). However, in 1995 populations of an additional two species (the European Bell Heather *E. cinerea* L. and South African *E. glandulosa* Thunb.) were found in a small area of disturbed remnant bushland bordering Mount Lofty House on the north-western boundary of Mount Lofty Botanic Gardens.

Erica cinerea from temperate, western Europe has numerous ornamental cultivars grown in southern Australia (Spencer 1997) and is a temperate, severe cold-tolerant, generally summer-flowering species from low, open heaths on acidic soils (Rozé 1993; Ojeda *et al.* 1998; Leith *et al.* 1999). In contrast, *E. glandulosa* is a long-lived, frost-tolerant, year-round but mainly autumn-flowering, species from tall fynbos on well-drained soils in the southern Cape region of South Africa between Mosselbaai and Port Elizabeth (Baker & Oliver 1967). *E. glandulosa* is cultivated as an ornamental shrub in South Africa and Europe (Baker & Oliver 1967; Nelson 1997), and although not currently listed as grown in Australian gardens (Spencer 1997), is naturalised in Australia, but with no locality or weed status details (AFFA 2001).

As these two species seem only to have naturalised recently in the Adelaide Hills, the populations were

Centre for Evolutionary Biology and Biodiversity, Environmental Biology, School of Earth and Environmental Sciences, Darling Building DP418, The University of Adelaide, SA 5005.

² Present address: SARDI, SA Aquatic Sciences Centre, 2 Hamra Ave, West Beach, SA 5024.

³ Correspondence author: john.conran@adelaide.edu.au.

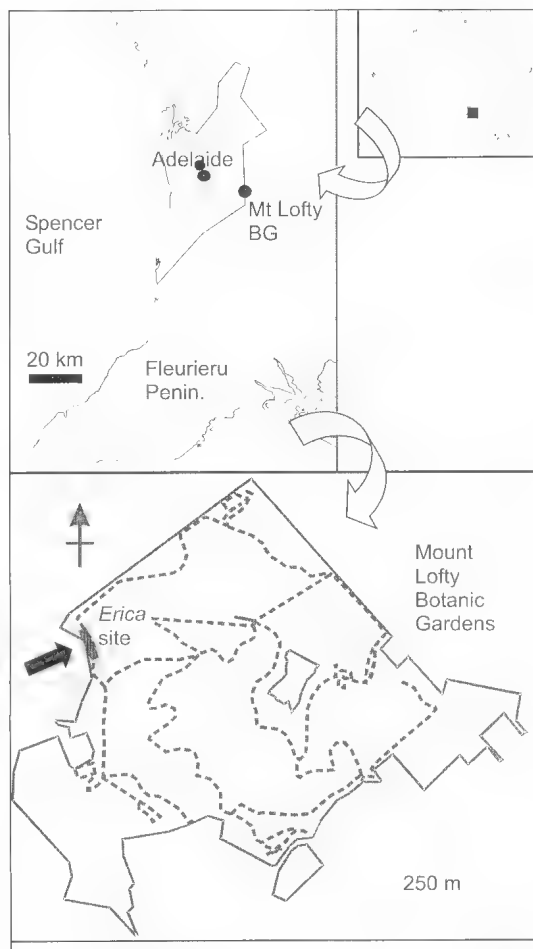


Fig. 1. Mount Lofty Botanic Gardens site showing the locality of the *Erica cinerea* and *E. glandulosa* colonies.

relatively small and confined to the one area. However, as they are morphologically dissimilar and come from different environments they may have different establishment strategies. Accordingly, the two aims of this study were:

To compare the reproductive biology of the two species to assess how their strategies might relate to any success or failure to establish.

To examine their population structure with particular emphasis on their potential fecundity, and to see if expansion had occurred after eight years.

Methods

The site

Mt Lofty Botanic Gardens is a 97 ha reserve located in the Adelaide Hills 13 km SE of Adelaide (34° 58' S, 138° 42' E, 670 m altitude) combining

extensive planted areas of exotics with a flora reserve of native *Eucalyptus obliqua* L'Hér. forest with sclerophyllous understorey (Haegi & Morley 1991). The area surveyed represents an approximately 10 x 100 m area of disturbed remnant eucalypt forest located on the NW side of the Gardens, close to the boundary fence with the grounds of Mount Lofty House (Fig. 1). The site understorey is a mixture of Epacridaceae, mainly Pink Ground Berry (*Acrotriche fasciculiflora* (Regel) Benth.) and Native Heath (*Epacris impressa* Labill.), other native shrubs, bracken fern (*Pteridium esculentum* (G. Forst.) Cockayne) and introduced shrubby weeds including Spanish Broom (*Cytisus scoparia* (L.) Link) and Tree Erica (*Erica arborea* L.).

Floral advertisement and rewards

Advertisement for pollinators can involve several simultaneous stimuli including visual, olfactory, and short range tactile cues, and may be considered as any stimulus which attracts visitors to a flower (Faegri & van der Pijl 1979).

Visual stimulus is a combined effect of the target colour (including combinations of colour and pattern) and the size shape of the target. Of primary importance is the pollinator's visual spectrum (the visual spectrum of insects differs from that of humans) which affects the contrast between the flower and the background foliage (Dafni 1992; Dyer 1996). Flowers of the two species were photographed using Kodak P-3200 B&W film bracketed at f8-f22 with and without a UV transmitting filter (Hoya U360) by a Pentax MEII Super with macro lens and G30-rated flash. The film was developed following manufacturer's instructions for 10 minutes at 21°C, allowing visualisation of the flowers from the perspective of different potential pollinators.

Because floral scent may be ephemeral, flowers were sealed in 30 mm glass vials for two hours in a warm, well-lit location and the vials were then opened and smelt (Bernhardt 1995). In addition, flowers were stained in 1% neutral red for 2 hours and rinsed in distilled water for 18 hours to detect possible osmophore-bearing regions (Dafni 1992; Bernhardt 1995). Nectar volume was measured using micro-sampling pipettes and electronic balances, with ten flowers from each of the two species sampled at various times of the day to allow for temporal variation in nectar production. Nectar composition of the two species was examined using thin layer paper chromatography. Nectar from five flowers of each species was extracted by washing with 5 µL of deionised water, and spotted onto a sheet of Whatman's No. 1 chromatography paper. Sugar standards were also added for glucose,

sucrose, fructose, maltose, and galactose and the chromatogram run using a solution of 12:3:5 n-butanol: acetic acid: water. After 24 hours, the paper was removed from the solvent, dried, sprayed with an indicator solution of 1% aniline, 1% diphenylamine and 4% phosphoric acid in acetone and baked at 85°C for five minutes (Neimietz & Hawker 1988). The relative intensity of each nectar component was coded according to the nectar classifications of Percival (1961) and Baker & Baker (1983).

Floral visitor behaviour was observed between 9 am and 4 pm (opening hours at Mt Lofty Gardens) over several days in Feb.-Mar. 1995, Sept. 2002 and Feb.-Mar. 2003 with observations mainly between 9 am and 1 pm, as pollinator activity was minimal in the afternoon. Birds were monitored from about 10 m using binoculars, and insects were netted, killed in jars with ethyl acetate fumes, examined under a binocular microscope and then washed briefly on a microscope slide with drops of absolute ethanol to remove any pollen. The resulting residue was mounted in a drop of 2.5% saturated aqueous Methyl Green and 2% saturated aqueous Phloxine in phenol glycerine jelly (Owczarzak 1952), and pollen identified by light microscopy.

Population structure and fecundity

Numbers of individuals of each of the two species were counted in order to obtain a total population count for the infested area. Twenty individuals of each species were then chosen at random, and the following information recorded for each:

- Number of shoots per plant
- Number of inflorescences on each shoot
- Number of flowers on each inflorescence
- Number of ovules per ovary
- Number of seeds per ovary

Results

Floral advertisement and rewards

Erica glandulosa is an erect species >1 m tall with large, orange-pink flowers in the leaf axils (Fig. 2B) which are classed as tubular-curved (Rebello *et al.* 1985) whereas *E. cinerea* is a ground hugging shrub with inflorescences of small violet-purple flowers (Fig. 2C) which are classified as urceolate (Rebello *et al.* 1985).

The violet-purple flowers of *E. cinerea* create an obvious contrast between the flower and its background (Fig. 3A). The corollas were classed as UV-light (pale) (Dafni 1992), with reflected shorter wavelength light making them high-contrast to the foliage. Reflectance was highest in buds and newly-opened flowers, with older (possibly no-longer receptive) flowers being less reflective and more like

the foliage.

Erica glandulosa has orange-pink flowers on a green background making for high visual contrast, but as the flowers reflect wavelengths outside the normal insect visual spectrum, they are likely to be low contrast to an insect (Richards 1986; Dyer 1996). The UV photographs showed low contrast between the flowers and foliage, although again newly-opened flowers were more reflective than older ones, and the lobes of recently-opened flowers (which visually showed a light greenish tinge), tended to be more UV reflective.

No obvious scent or evidence of osmophores was found in *E. glandulosa* suggesting that the plant's advertisement strategy does not involve scent. Although no obvious odour was detected in *E. cinerea*, two possible scent producing areas were identified. The edges of the sepals stained darkly and microscopic examination revealed specialised tissues of uncertain function, and the toothed anther appendages also stained heavily.

Erica glandulosa contained a mean of 0.5 ± 0.2 μ L of nectar; whereas although minute droplets were noticed on the annular nectary below the ovary in *E. cinerea*, the volume was too minute to measure accurately. Chromatography of *E. glandulosa* nectar revealed strong spots for glucose and fructose, with a weak spot for sucrose making the species SFG using the nectar composition coding system of Percival (1961) and hexose-rich following Baker & Baker (1983), whereas *E. cinerea* possessed all three sugars, but with a slight predominance of sucrose (SFG), thereby making it sucrose-rich.

Flowers of *E. glandulosa* were visited in the mornings by New Holland Honeyeaters (Meliphagidae: *Phylidonyris novaehollandiae* (Latham, 1790). These perched along the erect stems approaching the flowers from below, their curved beaks enabling them to access easily the slightly downward-curved, tubular flowers. The only observed visitors to *E. cinerea* were honey bees (*Apis mellifera* L., 1758)), and inspection of captured visiting bees found they carried only pollen from that species. *Erica cinerea* flowers were also observed to have had the corolla tubes chewed open from the side, suggesting that bees were also engaged in reward theft (Fig. 2D).

Population structure and fecundity

In the 1995 survey, there were 67 mature individuals of *E. glandulosa* aggregated as small groups of 2 – 5 plants and scattered across an area of about 1000 m², but with no evidence of juvenile or seedling plants in the area surveyed. In addition, there were 1,436 mature (flowering) individuals of *E. cinerea* within an area of about 80 m², as well as numerous seedlings. Within this, there was a smaller



27 m² area of more open *Acrotriche fasciculiflora* and *Epacris impressa* heath on the eastern (roadward) side which contained about 50 mature *E. cinerea* m⁻², and up to about 100 seedlings m⁻² whereas the surrounding area contained only about four mature individuals and 10–20 seedlings m⁻². In contrast, by 2002, whereas there were 54 mature *E. glandulosa* plants still scattered over the same area, the numbers of *E. cinerea* had fallen to only 34 adult plants in total, all within the original 27 m² area which had previously contained the bulk of the population (Table 1), and there was no evidence of seedlings.

Data from the first survey suggested that the populations are highly fecund, with numerous seeds per individual and high total estimated annual seed set for both taxa (Table 1). Nevertheless, in 2003 not only had populations of both species declined significantly, but fecundity was also reduced, mainly through fewer flowers and inflorescences per plant, resulting in a dramatic decrease in estimated total seed set for both species at the colony level.

Discussion

The area that the two species occupy is in the north-western corner of the Botanic Gardens and although part of a native flora reserve, is directly below Mount Lofty House and was previously part of those gardens. Possible scenarios for their initial establishment are that these two *Erica* spp. were planted on the bank at some time in the past and have persisted as a remnant population, or that they spread from the original gardens into the surrounding bushland.

Evidence from pollination studies in a number of ericaceous genera and *Erica* spp. in particular suggest that they are predominantly self-sterile (Anderson *et al.* 2000; Ng & Corlett 2000) or with limited self-compatibility (Aparicio & García-Martin 1996; Santandreu & Lloret 1999). Nevertheless, *E. cinerea* is regarded as both self- and cross-pollinating (Knuth 1909; Bannister 1965), with the slightly protogynous flowers effecting pollen transfer before the buds open (Hagerup 1951). The pollination biology of the two species studied here shows the different strategies in insect- and bird-pollinated Ericaceae. That pollination is successful at Mount Lofty is reflected in the high levels of seed set, and the plants have clearly benefited from the adaptation of local pollinators to a new food source. This might also explain the scarcity of nectar in the SA flowers despite reports of copious nectar in European studies (Bannister 1965).

Erica cinerea with relatively small, pale-purple, urceolate flowers falls into the entomophilous syndrome common in the genus (Knuth 1909; Rebelo *et al.* 1984; 1985). Insect visitors to European *Erica* spp. include honeybees, bumblebees, flies, moths and butterflies (Knuth 1909; Aparicio & García-Martin 1996; Santandreu & Lloret 1999) and Knuth (1909) listed a wide range of insects visiting *E. cinerea*, and reported corolla chewing and nectar theft by bumblebees. He also noted that pollination in this species was identical to that of *E. tetralix* L., where honeybees chew through the floral tubes because their c. 6 mm long mouthparts were too short to reach the nectaries of average-sized flowers (7 mm – the same as *E.*

TABLE 1. Summary of fecundity parameters for the two *Erica* spp. naturalised at Mt Lofty.

Parameter	n	<i>E. cinerea</i>			<i>E. glandulosa</i>		
		1992	2003	t or χ^2	1992	2003	t or χ^2
Plants per colony		1,436	34	1,428.0***	67	54	2.5 ns
Main stems per plant	20	5.0 \pm 1.7	4.7 \pm 1.9	0.7 ns	5.2 \pm 6.9	5.0 \pm 7.3	0.2 ns
Inflorescences per plant	20	18.8 \pm 8.2	10.3 \pm 12.2	8.4***	29.4 \pm 35.5	21.5 \pm 40.1	4.0*
Inflorescences per main stem	20	3.9 \pm 1.5	2.6 \pm 1.8	3.2*	6.2 \pm 1.1	4.1 \pm 1.8	5.5**
Flowers per inflorescence	100	6.6 \pm 4.8	6.2 \pm 5.7	2.5*	3.2 \pm 1.0	3.0 \pm 1.2	1.3 ns
Ovules per ovary	10	24.0 \pm 1.4	22.8 \pm 2.1	2.028 ns	708.0 \pm 122.3	692.9 \pm 173.1	1.7 ns
Seeds per ovary	10	3.4 \pm 1.4	3.1 \pm 1.6	0.5 ns	215.0 \pm 52.5	208.2 \pm 74.6	1.9 ns
Seeds per plant (estimated)		422	153	n/a	20,227	13,430	n/a
Total seeds per year (estimated)		605,992	5,202	n/a	1,355,209	725,220	n/a

counts compared using χ^2

Fig. 2. *Erica cinerea* and *E. glandulosa* habitat and habit. A. Habitat of *Eucalyptus obliqua* forest with sclerophyllous shrub and bracken understorey. B. *Erica glandulosa* habit. C. *E. cinerea* habit. D. *E. cinerea* flower showing damage by nectar thieves.

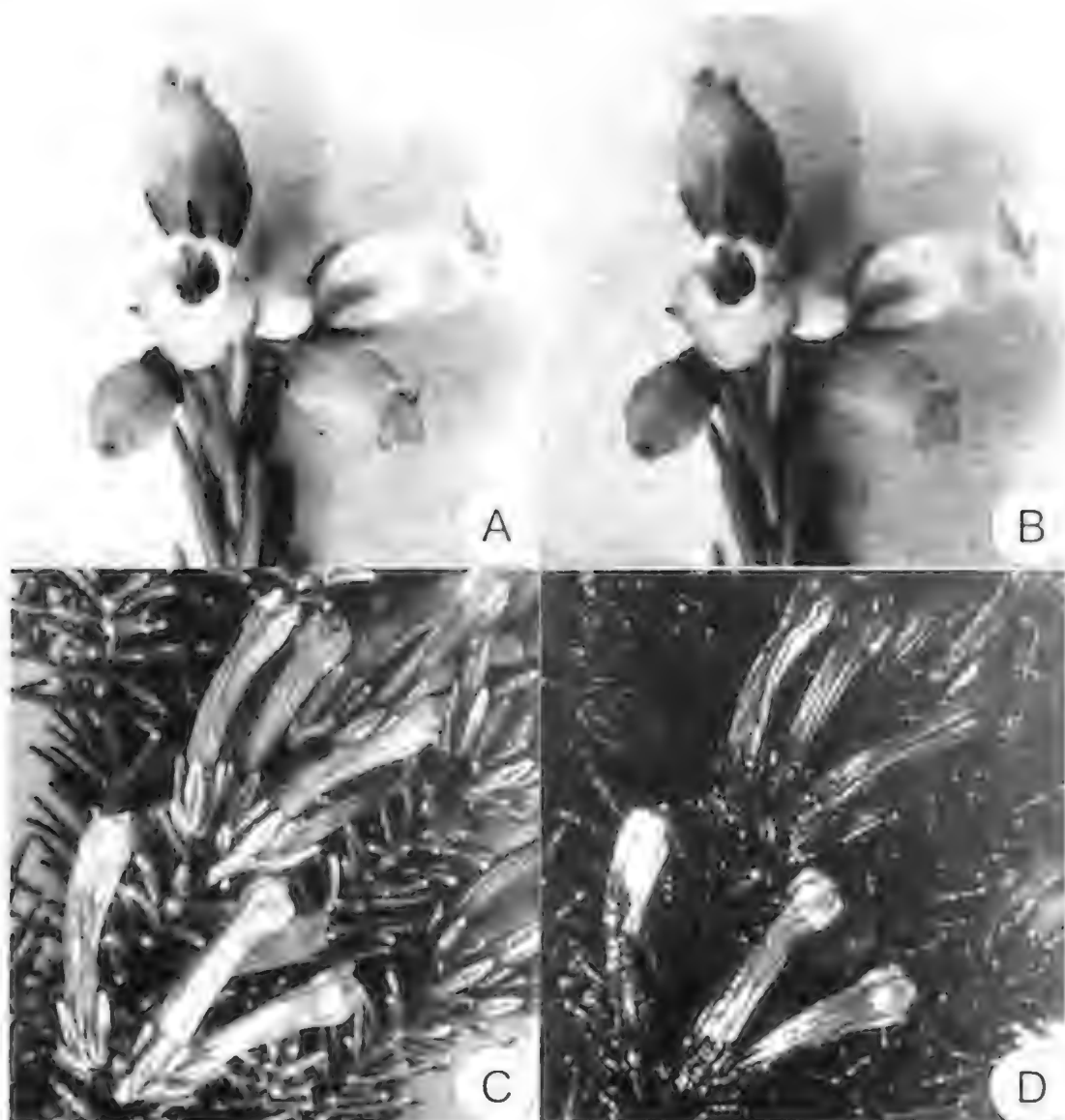


Fig. 3. Photographs of the two *Erica* spp. under visible (A, C) and UV (B, D) light. A-B, *Erica cinerea*. C-D, *E. glandulosa*.

cinerea). Nectar composition was similar to other European *Erica* species listed by Percival (1961) as visited extensively by honeybees, and the sucrose-rich nectar agrees with Baker & Baker's (1983) observation that bee-flowers with floral tubes > 6 mm are mainly "long-tongued" bee-flowers and generally sucrose-rich. Most *Erica* spp. are generally considered to be scentless, although there is a number of species reported with marked honey scents (Rebello *et al.* 1985). The anther appendages in *E. cinerea* are thought to position the anthers for entomophilous pollen delivery (Knuth 1909; Rebello

et al. 1985) but the presence of apparently glandular structures which stain strongly with neutral red suggests that they may also serve as osmophores, and warrants further investigation.

In contrast, *E. glandulosa* has orange-pink, tubular-curved, scentless flowers with copious nectar (Rebello *et al.* 1984; 1985), and the hexose-dominated nectar in *E. glandulosa* reflected the results found by Barnes *et al.* (1995) for several ornithophilous species of *Erica* sect. *Evanthe*. The members of sect. *Evanthe* are thought to have co-evolved for pollination with nectariniid Sunbirds

(Scott-Elliot 1890; Rebelo *et al.* 1984; 1985), which fill the same ecological niche as the honeyeaters seen visiting it in our study, although there is evidence also of pollination of some *Evanthe* spp. in South Africa by long-proboscid Nemestrinid flies (Manning *et al.* 1999). Although, the assertion by Baker & Baker (1983) that hexose-rich bird flowers are associated with passerines must be treated with some caution, given the dominance of sucrose-rich to sucrose-dominant *Evanthe* spp. reported by Barnes *et al.* (1995), numerous South African passerine-pollinated flowers do produce high volumes of very dilute, hexose-dominated nectar (Nicolson 2002). The orange-pink flowers showed only limited UV-reflectance, suggesting that they are not strongly adapted for insect pollination (Richards 1986; Dyer 1996), although tubular red flowers can be attractive to long-proboscid flies (Manning *et al.* 1999). The glandular hairs which cover all parts of this species except the corolla possibly help to deter would-be insect nectar thieves, similar to those ornithophilous *Erica* spp. with externally viscid corollas (Scott-Elliot 1890; Rebelo *et al.* 1985). Similarly, the presence of only anatomically rudimentary anther appendages in this species (Palser & Murty 1967; Hermann & Palser 2000) supports the assertion by Knuth (1909) and Rebelo *et al.* (1985) that they are involved in presenting the anthers primarily for entomophilous pollination. Nevertheless, if there is an anther appendage – osmophore connection, the loss of appendages in *E. glandulosa* would further support pollination by passerines with a poor sense of smell.

What is most apparent from this study is that despite initial apparent success, with high levels of both numbers of individuals and/or annual fecundity, neither species has managed to spread; in fact both have declined in terms of above ground biomass. This is particularly the case for *E. cinerea* where this previously abundant plant is now very scarce at the site, and the remaining plants are smaller and with lower fecundity than in 1995. The most likely explanation for this decline in *E. cinerea* is a combination of competition (Bannister 1965) and litter accumulation (Mallik *et al.* 1984). Shading can determine species composition in heaths and cause removal of understorey species (Vilà & Sardans 1999), and crowding or shading by neighbours reduced fecundity in *Erica multiflora* L. (Vilà & Terradas 1995, 1998). In 1995 *E. cinerea* was most abundant in a small area of relatively open epacrid-dominated heath, but by 2003 this, like the rest of the surveyed area, had been overgrown by *Pteridium* and *E. arborea*, the latter of which outgrows *Acrotriche fasciculiflora* under dry conditions (Gehrig 2000). *Erica cinerea* prefers more temperate, mesic conditions than *E. arborea*

(Ojeda *et al.* 1998) and would be disadvantaged under the hot dry summers seen in South Australia. Similarly, it grows mainly in low open heaths (Bannister 1965; Rozé 1993), whereas *E. arborea* generally grows better under forest cover or shade (Ojeda *et al.* 2000). In contrast, *E. glandulosa* was apparently able to compete better for space, being of similar size to the invading bracken and shrubs, although crowding may have reduced fecundity, as seed set in resprouter *Erica* species is correlated with main shoot size and vigour (Riba 1998).

Establishment in *E. cinerea* is mainly by seed, and flowering is improved by higher nitrogen levels (Leith *et al.* 1999), although seed set and germination rate drops with population age (Mallik *et al.* 1984). Germination occurs in the presence of light, with 20–40% of the seeds germinating the season after they are shed, nevertheless, heat shock substantially increases germination rates (Bannister 1965), whereas litter accumulation inhibits germination and seedling survival (Mallik *et al.* 1984). *Erica cinerea* grows preferentially in short open heath, and recovers more slowly to from fire than taller heaths (Rozé 1993), although its seeds can survive for at least 30–40 years in the soil seedbank (Mallik *et al.* 1984; Thompson & Band 1997). *Erica* seeds in the upper 2–5 cm soil depth tend to survive fire better than many other Mediterranean woody heath species (Ferrandis *et al.* 1999), but although *E. cinerea* can produce up to a million seeds m⁻², there is seedbank mortality of 20–40% after the first year, as well as low seedling survival (Webb 1986).

In contrast, *E. glandulosa* is a resprouter (Ojeda 1998) – an unusual condition amongst Cape *Erica* species – although germination in many Cape *Erica* spp. is also smoke-triggered (Brown *et al.* 1993), and it is possible that the absence of seedlings of this species, despite the large numbers of seeds produced, may be related to the lack of a suitable trigger, and/or the fact that many fire-dependent heath species do not germinate well under conditions of high litter and standing biomass (Rozé 1993; Lloret & Vilà 1997). The breeding system of this species is as yet unknown, and further studies would be useful to determine whether it is cross-, self-pollinated or both, as this has implications for the ability of isolated individuals to set seed and spread further.

In conclusion, the evidence suggests that although the populations of these two species appear to be in decline, despite their initial success and apparently high potential fecundity, were a fire or other disturbance to alter the conditions at the site, they may well be able to recover or expand, via the seedbank, representing a future weed problem awaiting an environmental trigger. However, as

bracken and *E. arborea* also recolonise quickly after fire or other disturbances, and frequent, repeated aerial biomass removal of the latter is needed to reduce its aggressive regrowth capacity (Riba 1998), it is possible that they may prevent further spread by the two new *Erica* spp. although this will require long term monitoring of the site, especially if the area were to be burnt in the future. Nevertheless, in either scenario, the real threat is to the native sclerophyllous understorey vegetation, as there are additional and apparently successful introduced competitors for the limited resources at the site.

Acknowledgements

The former Department of Botany, now Discipline of Environmental Biology within the School of Earth and Environmental Sciences, The University of Adelaide is thanked for the provision of resources for this project, the initial phase of which was undertaken by DT as part of a B.Sc. (Hons) degree. The director of the Adelaide Botanic Gardens and staff of the Mount Lofty Botanic Gardens are thanked for permission to undertake the research in the gardens.

References

- AFFA (2001) "Annual Report 2000-2001" (Department of Agriculture, Fisheries and Forestry, Australia, Canberra).
- ANDERSON, G. J., BERNARDELO, G., LOPEZ, P., STUESSY, T. F. & CRAWFORD, D. J. (2000) Dioecy and wind pollination in *Pernettya rigida* (Ericaceae) of the Juan Fernandez Islands. *Bot. J. Linn. Soc.* **132**, 121-141.
- APARICIO, A. & GARCIA-MARTIN, F. (1996) The reproductive biology and breeding system of *Erica andevalensis* Cabezedo & Rivera (Ericaceae), an endangered edaphic endemic of southwestern Spain - implications for its conservation. *Flora* **191**, 345-351.
- BAKER, H. A. & OLIVER, E. G. H. (1967) "Ericas in Southern Africa" (Purnell and Sons, Cape Town).
- BAKER, H. G. & BAKER, I. (1983) Floral nectar sugar constituents in relation to pollinator type pp. 117-141 In Jones, C. E. & Little, R. J. (Eds) "Handbook of Experimental Pollination Biology" (Van Nostrand Reinhold, New York).
- BANNISTER, P. (1965) Biological flora of the British Isles: *Erica cinerea* L. *J. Ecol.* **53**, 527-542.
- BARNES, K., NICOLSON, S. W. & VAN WYK, B.-E. (1995) Nectar sugar composition in *Erica*. *Biochem. Syst. Ecol.* **23**, 419-423.
- BERNHARDT, P. (1995) The floral ecology of *Dianella caerulea* var. *assera* (Phormiaceae). *Cunninghamia* **4**, 9-20.
- BROWN, N. A. C., KOIZE, G. & BOTHJA, P. A. (1993) The promotion of seed germination of Cape *Erica* species by plant-derived smoke. *Seed Sci. Tech.* **21**, 573-580.
- CSHURES, S. & EDWARDS, R. (1998) "Potential Environmental Weeds in Australia" (Queensland Department of Natural Resources, Coopers, Qld).
- DAFNI, A. (1992) "Pollination Biology: A Practical Approach" (IRL Press, Oxford).
- DYER, A. G. (1996) Reflection of near-ultraviolet radiation from flowers of Australian native plants. *Austral. J. Bot.* **44**, 473-488.
- FALGRI, K. & VAN DER PHIL, L. (1979) "The Principles of Pollination Ecology, 3rd Revised Edition" (Pergamon, Oxford).
- FERRANDIS, P., HERRANZ, J. M. & MARTINEZ-SANCHEZ, J. J. (1999) Fire impact on a maquis soil seed bank in Cabaneros National Park (central Spain). *Israel Journal of Plant Sciences*. **47**, 17-26.
- GEHRIG, S. (2000) "Getting to know *Erica*: Investigations into an environmental woody weed of the southern Mount Lofty Ranges, South Australia" (Environmental Biology, School of Earth and Environmental Sciences, The University of Adelaide). Unpublished Honours Thesis.
- GIMMINGHAM, C. H., CHAPMAN, A. R. & WEBB, N. R. (1979) European heathlands pp. 365-413 In Specht, R. L. (Ed.) "Ecosystems of the World, 9A, Heathlands and Related Shrublands" (Elsevier Scientific Pub. Co., Amsterdam).
- GLUTHRIE, F. & BOIUS, H. (1905) *Erica* pp. 4-315 In Thiselton-Dyer, W. T. (Ed.) "Flora Capensis, Vol. 4" (L. Reeve, Ashford, Kent).
- HAEGI, L. & MORLEY, B. D. (1991) "Mount Lofty Botanic Garden Catalogue of Plants 1991" (The Botanic Gardens of Adelaide and State Herbarium of South Australia, Adelaide).
- HAGERUP, O. (1951) Pollination in the Faroes - in spite of rain and poverty of insects. *Det Kgl Dansk. Vidensk. Selsk. Biol. Meddel.* **18**, 1-48.
- HERMANN, P. M. & PALSER, B. F. (2000) Stamen development in the Ericaceae. I. Anther wall, microsporogenesis, inversion, and appendages. *Amer. J. Bot.* **87**, 934-957.
- JESSOP, J. P. & TOELKEN, H. R., Eds (1986) "Flora of South Australia" (South Australian Government Printer, Adelaide).
- KNUTH, P. (1909) "Handbook of Flower Pollination Vol. 3" (Clarendon Press, Oxford).
- LITTH, I. D., HICKS, W. K., FOWLER, D. & WOODIN, S. J. (1999) Differential responses of UK upland plants to nitrogen deposition. *New Phytol.* **141**, 277-289.
- LLORIT, F. & VILA, M. (1997) Clearing of vegetation in Mediterranean garrigue - response after a wildfire. *Forest Ecol. Manag.* **93**, 227-234.
- MALLIK, A. U., HOBBS, R. J. & LEGG, C. J. (1984) Seed dynamics in *Calluna-Acrotostaphylos* heath in north-eastern Scotland. *J. Ecol.* **72**, 855-871.
- MANNING, J. C., GOLDBLATT, P. & WINTER, P. (1999) Two new species of *Gladiolus* (Iridaceae: Ixioidae) from South Africa and notes on long-proboscid fly pollination in the genus *Bothalia* **29**, 217-223.
- NEIMIETZ, C. & HAWKER, J. S. (1988) Sucrose accumulation in red beet vacuoles by UDP glucose-dependent group translocation - fact or artefact? *Austral. J. Pl. Physiol.* **15**, 359-366.
- NELSON, E. C. (1997) *Erica* pp. 485 In Cullen, J., Walter, S. M., Brady, A., Brickell, C. D., Green, P. S., Lewis, J., Matthews, V. A., Webb, D. A., Yeo, P. F. & Alexander, J. C. M. (Eds) "The European Garden Flora, Vol. V. Limnanthaceae to Oleaceae - Dicotyledons (Part III)" (Cambridge University Press, Cambridge).
- NG, S. C. & CORLETT, R. T. (2000) Genetic variation and structure in six *Rhododendron* species (Ericaceae) with contrasting local distribution patterns in Hong Kong, China. *Molec. Ecol.* **9**, 959-969.

- NICOLSON, S. W. (1992) Pollination by passerine birds: why are the nectars so dilute? *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology* **131**, 645-652.
- OJEDA, F. (1998) Biogeography of seeder and resprouter *Erica* species in the Cape Floristic Region - where are the resprouters? *Biol. J. Linn. Soc.* **63**, 331-347.
- _____, ARROYO, J. & MARAÑÓN, T. (2000) Ecological distribution of four co-occurring Mediterranean heath species. *Ecogr.* **23**, 148-159.
- _____, _____ & _____ (1998) The phytogeography of European and Mediterranean heath species (Ericoideae, Ericaceae) - a quantitative analysis. *J. Biogeogr.* **25**, 165-178.
- OWCZARZAK, A. (1952) A rapid method for mounting pollen grains. *Stain Tech.* **27**, 249-251.
- PALSER, B. F. & MURTY, Y. S. (1967) Studies of floral morphology in the Ericales. VIII. Organography and vascular anatomy in *Erica*. *Bull. Torrey Bot. Club* **94**, 243-320.
- PERCIVAL, M. S. (1961) Types of nectar in angiosperms. *New Phytol.* **60**, 235-281.
- REBELO, A. G., SIEGFRIED, W. R. & CROWE, A. A. (1984) Avian pollinators and the pollination syndromes of selected Mountain Fynbos plants. *S. Afr. J. Bot.* **3**, 285-296.
- _____, _____ & OLIVER, E. G. H. (1985) Pollination syndromes of *Erica* species in the south-western Cape. *S. Afr. J. Bot.* **51**, 270-280.
- RIBA, M. (1998) Effects of intensity and frequency of crown damage on resprouting of *Erica arborea* L. (Ericaceae). *Acta Oecol.* **19**, 9-16.
- RICHARDS, A. J. (1986) "Plant Breeding Systems" (Allen and Unwin, London).
- ROZÉ, F. (1993) Plant recolonisation after fire in Brittany littoral heathlands. *Acta Oecol.* **14**, 529-538.
- SANTANDREU, M. & LLOFF, F. (1999) Effect of flowering phenology and habitat on pollen limitation in *Erica multiflora*. *Can. J. Bot.* **77**, 734-743.
- SCOTT-ELLIOT, G. F. (1890) Ornithophilous flowers in South Africa. *Ann. Bot.* **4**, 265-280.
- SPECHT, R. (1979) The sclerophyllous (heath) vegetation of Australia: the eastern and central states pp. 125-210 *In* Specht, R. (Ed.) "Ecosystems of the World, 9A, Heathlands and Related Shrublands" (Elsevier Scientific Pub. Co., Amsterdam).
- _____, _____ (1981) Heathlands pp. 253-275 *In* Groves, R. (Ed.) "Australian Vegetation" (Cambridge University Press, Melbourne).
- SPENCER, R., Ed. (1997) "Horticultural Flora of South-Eastern Australia Vol. 2. Flowering Plants, Dicotyledons, Part 1" (UNSW Press, Sydney).
- THOMPSON, K. & BAND, S. R. (1997) Survival of a lowland heathland seed bank after a 33-year burial. *Seed Sci. Res.* **7**, 409-411.
- VILÁ, M. & SARDANS, J. (1999) Plant competition in Mediterranean-type vegetation. *J. Veg. Sci.* **10**, 281-294.
- _____, _____ & TERRADAS, J. (1995) Effects of competition and disturbance on the resprouting performance of the Mediterranean shrub *Erica multiflora* L. (Ericaceae). *Amer. J. Bot.* **82**, 1241-1248.
- _____, _____ & _____ (1998) Neighbour effects on *Erica multiflora* (Ericaceae). Reproductive performance after clipping. *Acta Oecol.* **19**, 139-145.
- WEBB, D. A. & RIX, E. M. (1972) *Erica* pp. 5-8 *In* Tutin, T. G., Heywood, V. H., Burges, N. A., Moore, D. M., Valentine, D. H., Walters, S. M. & Webb, D. A. (Eds) "Flora Europaea, Vol. 3" (Cambridge University Press, Cambridge).
- WEBB, N. R. (1986) "Heathlands" (Collins, London).

THE MYRTLE SPRINGS METEORITE: A CHONDRITE (H4) FROM SOUTH AUSTRALIA¹

BY *M. ZBIK** & *A. PRING***

Summary

Zbik, M. & Pring, A. (2004) The Myrtle Springs meteorite: A (H4) chondrite from South Australia. *Trans. R. Soc. S. Aust.* 128(1), 33-36, 31 May, 2004.

A single stone of 52.99 g was found 30 km west of the Old Myrtle Springs homestead on the Lake Torrens Plains, (30° 27' 13.8'' S, 137° 59' 24.6'' E). The chondrules in the meteorite are well defined and the dark matrix consists of fine olivine and pyroxene grains. Olivine (Fa_{17.2 ± 0.6}), orthopyroxene (Fs_{15.7 ± 0.7}Wo_{1.8 ± 0.8}), clinopyroxene (Wo_{22 ± 2.0}Fs_{14 ± 1.0}), troilite and chromite are present. Radial pyroxene chondrules, porphyritic pyroxene chondrules, granular olivine-pyroxene porphyritic and olivine-pyroxene chondrules are abundant in the meteorite. Cryptocrystalline pyroxene chondrules and pyroxene-olivine chondrules are rare. Based on texture and mineral chemistry, the Myrtle Springs meteorite is classified as an H4 chondrite of shock stage S1-2, weathering grade W4.

Key Words: Myrtle Springs, meteorite, chondrite.

THE MYRTLE SPRINGS METEORITE: A CHONDRITE (H4) FROM SOUTH AUSTRALIA¹

by M. ZBIK* & A. PRING**

Summary

ZBIK, M. & PRING, A. (2004) The Myrtle Springs meteorite: A (H4) chondrite from South Australia. *Trans. R. Soc. S. Aust.* **128**(1), 33-36, 31 May, 2004.

A single stone of 52.99 g was found 30 km west of the Old Myrtle Springs homestead on the Lake Torrens Plains, (30° 27' 13.8" S, 137° 59' 24.6" E). The chondrules in the meteorite are well defined and the dark matrix consists of fine olivine and pyroxene grains. Olivine ($\text{Fa}_{17.2 \pm 0.6}$), orthopyroxene ($\text{Fs}_{15.7 \pm 0.7}\text{Wo}_{1.8 \pm 0.8}$), clinopyroxene ($\text{Wo}_{22.2 \pm 0.8}\text{Fs}_{14.1 \pm 1.0}$), troilite and chromite are present. Radial pyroxene chondrules, porphyritic pyroxene chondrules, granular olivine-pyroxene porphyritic and olivine-pyroxene chondrules are abundant in the meteorite. Cryptocrystalline pyroxene chondrules and pyroxene-olivine chondrules are rare. Based on texture and mineral chemistry, the Myrtle Springs meteorite is classified as an H4 chondrite of shock stage S1-2, weathering grade W4.

KEY WORDS: Myrtle Springs, meteorite, chondrite

Introduction

The meteorite was found by Mr Don McColl of Glenside, South Australia on the 11th of July 2002, while he was searching for tektites on Old Myrtle Springs homestead on the Lake Torrens Plain. The exact location as determined by GPS is 30° 27' 13.8" S, 137° 59' 24.6" E. The site is some 21 km due west of the Old Myrtle Springs homestead and some 40 km WNW of Leigh Creek South township (Fig. 1). Mr McColl undertook a detailed search of the area for more pieces of the meteorite, but none was found. Given that there are few geographical place names in the area, we propose the name Myrtle Springs, the nearest geographical name. A report of the meteorite name and petrological details have been submitted to the Meteorite Nomenclature Committee and approval has been granted. Mr Don McColl surrendered the meteorite to the Museum in accordance with the South Australian Museum Act and was presented with a bronze medallion to commemorate the find.

Macroscopic Description

The meteorite is a 52.99 g single stone, shaped like a flattened rounded pebble about 4 cm in diameter and 2 cm thick and covered with fragments of a weathered brown crust (Fig. 2). The distinctive crust, 1 mm thick, is probably desert patina rather than a fusion crust. The silicate minerals throughout the interior of the stone are dark brown in colour and this

together with the desert patina, indicate that the meteorite has been exposed to the weather for a prolonged time. Metal is not present in the meteorite and it appears to have been oxidised to goethite and staining the matrix brown. A few unoxidized grains of troilite however, are still present, so the meteorite has not been completely oxidized. The extent of oxidation of the Myrtle Springs meteorite indicates some degree of antiquity for the fall, but it is rather difficult to judge the terrestrial age of the fall, possibly 20,000 to 35,000 years based on the weathering state (Wlotzka 1993). Jull *et al.* (1993) found only a weak correlation between the degree of

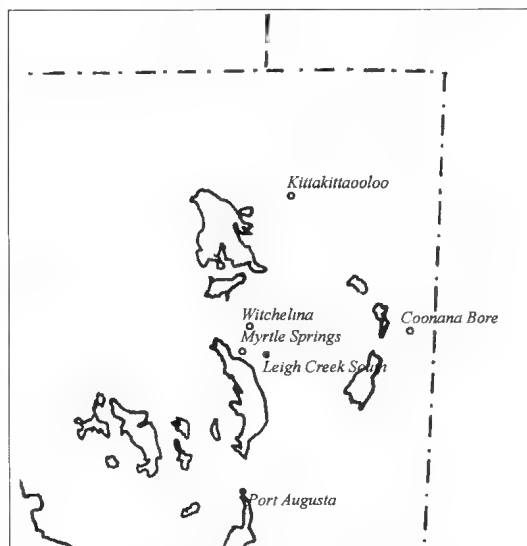


Fig. 1. Map showing the distribution of H4 chondrites in north eastern South Australia.

This paper is dedicated to the late David Williams an intrepid tektite hunter who passed away 7th February 2003.

* Ian Wark Research Institute, University of South Australia, Mawson Lake, Adelaide, South Australia 5095.

** Department of Mineralogy, South Australian Museum, North Terrace, Adelaide, South Australia 5000.

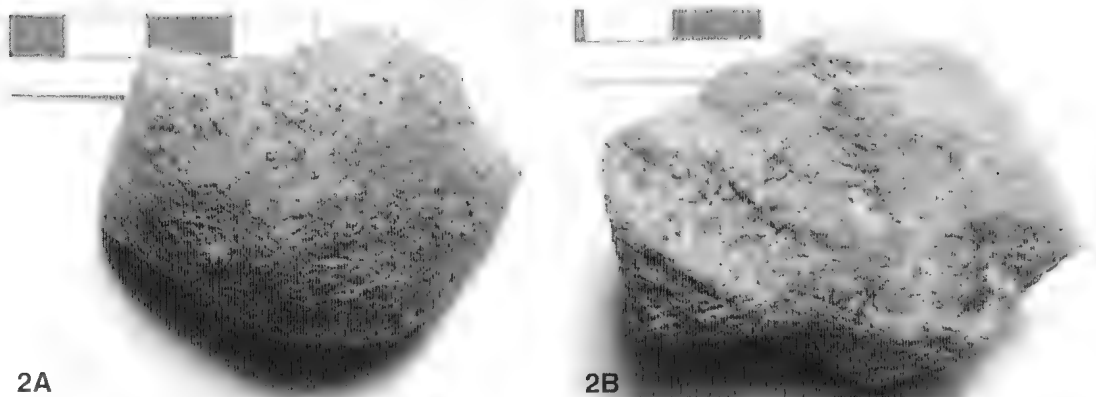


Fig. 2. Upper and lower surfaces of the Myrtle Springs meteorite showing the shape of the stone and the weathered brown desert patina crust. The scale bar is marked in centimetres.

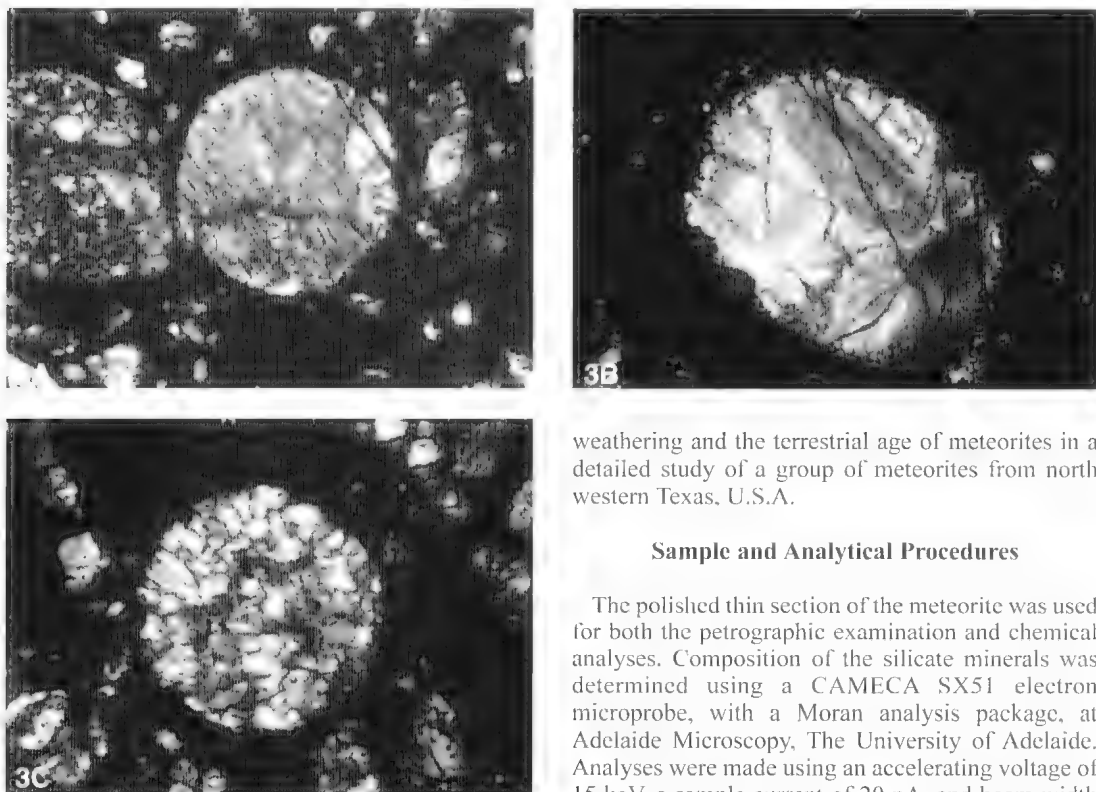


Fig. 3. Different types of chondrules in the Myrtle Springs meteorite. (a) Barred olivine chondrule (BO), composed of the olivine bars and mesostasis in centre of micrograph and granular olivine pyroxene chondrule (GOP) to the left side (photo is 1.5 mm). (b) Elliptically shaped cryptocrystalline pyroxene olivine chondrules (C) display unusual wavy extinction probably due to shock metamorphism (photo is 1.5 mm). (c) Porphyritic pyroxene olivine (POP) chondrule with poikilitic structure (photo is 1.5 mm).

weathering and the terrestrial age of meteorites in a detailed study of a group of meteorites from north western Texas, U.S.A.

Sample and Analytical Procedures

The polished thin section of the meteorite was used for both the petrographic examination and chemical analyses. Composition of the silicate minerals was determined using a CAMECA SX51 electron microprobe, with a Moran analysis package, at Adelaide Microscopy, The University of Adelaide. Analyses were made using an accelerating voltage of 15 keV, a sample current of 20 nA, and beam width of 0.1 μm .

Mineralogy

In thin section the meteorite is generally brown due to the goethite staining which permeates all of the section. The chondrules are clearly visible but they are extensively fractured. They are typically between 0.5 and 1 mm in diameter, but a few measuring more than 2 mm in diameter were noted.

The chondrules observed in the thin section are clearly defined which is typical in low petrologic type, but may have been additionally enhanced by the preferential weathering and iron oxide staining of the matrix. The chondrules and chondrule fragments are composed predominantly of olivine and pyroxene. Some chondrules display cryptocrystalline structure. Using the classification system of Wasson (1993), a number of distinct chondrule types can be identified in the meteorite. Barred olivine chondrules (BO), with pyroxene-plagioclase mesostasis between the olivine bars, are common (Fig. 3a). Cryptocrystalline pyroxene and pyroxene-olivine chondrules (C) are rare; those few observed vary in size and shape and display strong wavy extinction. These C-type chondrules are mineralogically heterogeneous, with in some areas pyroxene and others olivine (Fig. 3b). Radial pyroxene chondrules (RP) are common, and display a range of crystal sizes but nucleation appears to have occurred at a single point on the rim of the chondrules. Abundant are porphyritic pyroxene (PP) chondrules, granular olivine-pyroxene chondrules (GOP) (Fig. 3a, on the left-hand side), and porphyritic olivine-pyroxene chondrules (POP). Porphyritic chondrules contain fine and coarse grained, euhedral olivine crystals and display a poikilitic texture (Fig. 3c). Chondrules vary in shape, whereas the small chondrules, those below 1 mm, are generally round, the larger are often more oval and less regular in outline. Turbid cryptocrystalline mesostasis between olivine and pyroxene crystals is present and has a plagioclase/pyroxene-like composition but the analyses were non-stoichiometric. Distinct plagioclase grains were not found during petrological examination or microprobe analysis.

The matrix of the meteorite does not appear to have been recrystallised and consists of fine-grained olivine and pyroxene fragments but it is greatly obscured by the goethite staining making it difficult to study. Accessory chromite and troilite grains were detected in microprobe investigation. A number of quartz grains, aeolian in origin, were cemented into the secondary limonitic desert patina making crust around meteorite.

Selected electron microprobe analyses for the Myrtle Springs meteorite are given in Table 1. The olivine in the Myrtle Springs meteorite is equilibrated, with a mean fayalite content of $Fa_{17.2 \pm 0.6}$ (mean of 18 analyses). The Ca-poor pyroxene is uniform and shows only a narrow variation in composition with mean ferrosilite content of $Fs_{15.7 \pm 0.7}$, and wollastonite content of $Wo_{1.8 \pm 0.8}$ (mean of 20 analyses). The Ca-rich pyroxene is somewhat variable in composition with mean ferrosilite content of $Fs_{14.0 \pm 1.0}$, and wollastonite content of $Wo_{2.7 \pm 0.2}$ (mean of 15 analyses).

Classification

The Myrtle Springs meteorite has been classified as an H4 chondrite. The olivine ($Fa_{17.2 \pm 0.6}$) and Ca-poor pyroxene ($Fs_{15.7 \pm 0.7}$) compositions are within the range of the H chondrites (Keil & Fredriksson 1964). The equilibrated mineral compositions of the olivine and Ca-poor pyroxene, the presence of about 20% of the polysynthetically twinned Ca-rich pyroxenes, the lack of recrystallisation of the matrix, the well-defined chondrule boundaries and the glassy mesostases all indicated that the Myrtle Springs meteorite belongs to petrological type 4 classification of Van Schmus & Wood (1967). The wollastonite content in the low-calcium pyroxene is within the range found in H4 chondrites (Scott *et al.*, 1986). Van Schmus and Wood acknowledge that in their classification scheme that petrological type 4 is defined by relatively ambiguous characteristics as it represents a transition between extremely variable olivine and pyroxene compositions (type 3) and the uniform compositions (type 5). We choose type 4 rather than type 5 because of the abundance of clinopyroxene; type 5 chondrites have only very minor clinopyroxene.

Most olivine and pyroxene grains display sharp extinction and irregular fracture crystals in the Myrtle Springs chondrite. Some pyroxene display weak undulatory extinction. Both are indicative of the meteorite having been unshocked or only very weakly shocked after metamorphism. According to the classification scheme of Stöffler *et al.* (1991), the shock facies is estimated to be S1-2 (or i.e.) unshocked to very weakly shocked. The oxidation of approximately 95% of the original metal and troilite in the meteorite indicates weathering state W4 on the classification scheme of Wlotzka (1993).

Other H4 chondrites from North Eastern South Australia.

There are a number of other H4 group meteorites known from the north eastern region of South Australia (Fig. 1). The Kittakittaooloo meteorite was found in 1970 about 1 km NW of Lake Kittakittaooloo (28° 2' S, 138° 8' E) and has an olivine composition of $Fa_{18.9}$ (Graham *et al.* 1985). The Coonana meteorite was found in 1962 near Coonana Bore (29° 51' S, 140° 42' E) and has an $Fa_{19.2}$ olivine composition (Graham *et al.* 1985). Both of these meteorite localities are rather remote from Myrtle Springs being approximately 270 km north and 250 km ENE, respectively, of the site. The Witchelina meteorite was found in 1920 in the area of Witchelina homestead (30° S, 138° E), only 40 km north of the Myrtle Springs homestead, and it is possible that the two meteorites might be part of the

TABLE 1. *Representative electron microprobe analyses (wt. %) of selected minerals in Myrtle Springs meteorite.*

OXIDE (No. Analyses)	Olivine (18)	Ca-poor pyroxene (20)	Ca-rich pyroxene (15)
SiO ₂	39.26	56.42	49.60
TiO ₂	0.05	0.10	0.24
Al ₂ O ₃	0.04	0.41	3.41
FeO	16.13	10.38	8.83
MnO	0.48	0.52	0.47
MgO	43.41	30.58	22.86
CaO	0.04	0.94	10.77
Cr ₂ O ₃	0.40	0.30	0.91
Total	99.76	99.65	97.09

same fall. Unfortunately the locality details for the original site for the Witchelina find are sketchy and only approximate. The Witchelina meteorite was a 3.6 kg single stone and is coated with a distinctive fusion crust. Analysis gave an olivine composition of Fa_{19.1} (Graham *et al.* 1985), slightly more iron-rich than Myrtle Springs. Witchelina, however is a much

fresher stone. The metal has not been oxidized and metal and troilite are estimated to constitute around 3% of the meteorite. This indicates a weathering state of W1 or W2 and a terrestrial age of only a few thousand years. The ground mass colour has a distinctly greyish brown tone rather than reddish brown. While it might be expected, given the difference in size between Myrtle Springs and Witchelina, that the former would show the effects of weathering to a somewhat greater degree than the larger mass, but probably not to this extent. The difference in olivine composition, the presence of the fusion crust, and fresh metal in Witchelina all indicate that the two meteorites are not part of the same fall.

Acknowledgments

The authors wish to thank Mr Angus Netting and Mr John Terlet, of Adelaide Microscopy, The University of Adelaide, for assistance with the electron microprobe analyses. We wish to thank the editor and the two referees for their detailed and helpful comments on the manuscript.

References

- GRAHAM, A. L., BEVAN, A. W. R. & HUTCHINSON, R. (1985) *Catalogue of meteorites*. 4th edition. British Museum (Natural History) London. 460pp.
- JULL, A. J., DONAHUE, D. J., CIELASZYK, E. & WLOTZKA, F. (1993) Carbon-14 terrestrial ages and weathering of 27 meteorites from the southern high plains and adjacent area (USA) *Meteoritics* **28**, 188-195.
- KEIL, K. & FREDRIKSSON, K. (1964) The iron, magnesium and calcium distribution in coexisting olivines and rhombic pyroxenes of chondrites. *J. Geophys. Res.* **69**, 3487-3515.
- SCOTT, E. R. D., TAYLOR, G. J. & KEIL, K. (1986) Accretion, metamorphism, and brecciation of ordinary chondrites: Evidence from petrologic studies of meteorites from Roosevelt County, New Mexico. *Proc Lunar Planet. Sci. Conf. 17th*, E115-E123.
- STOFFLER, D., KEIL, K. & SCOTT, E. R. D. (1991) Shock metamorphism of ordinary chondrites. *Geochim. Cosmochim. Acta* **55**, 3845-3867.
- VAN SCHMUS, W. R. & WOOD, J. A. (1967) A chemical-petrologic classification for the chondritic meteorites. *Geochim. Cosmochim. Acta* **31**: 747-765.
- WASSON, J. T. (1993) Constraints on chondrule origins. *Meteoritics* **28**, 14-28.
- WLOTZKA, F. (1993) A weathering scale for the ordinary chondrites. *Meteoritics* **28**, 460.

EXPECTED LIFETIME IN SOUTH AUSTRALIA 1841-1996

BY P. I. LEPPARD, G. M. TALLIS & C. E. M. PEARCE*

Summary

Leppard, P. I., Tallis, G. M. & Pearce, C. E. M. Expected lifetime in South Australia 1841 – 1996. *Trans. R. Soc. S. Aust.* 128(1), 37-42, 31 May, 2004.

For each sex, population life tables have been calculated from mortality data associated with the age-specific population counts produced by each of the twenty-five population censuses that have been conducted in South Australia from 1841 until 1996. Estimates of expected lifetime have been derived separately for males and females for each census year. The computationally intensive statistical method of the bootstrap has been used to calculate a statistical sampling error for each estimate of expected lifetime. The results show generally increasing trends: from approximately 44 years and 48 years in 1841, to 75 years and 81 years in 1996, for males and females respectively.

Key Words: Expected lifetime, life expectancy, bootstrap standard error, South Australia.

EXPECTED LIFETIME IN SOUTH AUSTRALIA 1841 – 1996.

by P. I. LEPPARD*, G. M. TALLIS & C. E. M. PEARCE

Summary

LEPPARD, P. I., TALLIS, G. M. & PEARCE, C.E.M. Expected lifetime in South Australia 1841 – 1996. *Trans. R. Soc. S. Aust.* **128**(1), 37–42, 31 May, 2004.

For each sex, population life tables have been calculated from mortality data associated with the age-specific population counts produced by each of the twenty-five population censuses that have been conducted in South Australia from 1841 until 1996. Estimates of expected lifetime have been derived separately for males and females for each census year. The computationally intensive statistical method of the bootstrap has been used to calculate a statistical sampling error for each estimate of expected lifetime. The results show generally increasing trends; from approximately 44 years and 48 years in 1841, to 75 years and 81 years in 1996, for males and females respectively.

KEY WORDS: Expected lifetime; life expectancy; bootstrap standard error; South Australia.

Introduction

Expected lifetime or life expectancy, meaning the average length of life from birth until death, is often used as a composite indicator of the health and social conditions of a human population. Expected lifetime is a single value that summarises the prevailing mortality experience of a defined population of individuals, and consequently provides a means by which the mortality patterns of different populations can be conveniently compared. The progress in the development of the general well-being of a particular population can also be assessed by a time sequence of relevant expected lifetime values. Alternatively, expected lifetime can be cautiously interpreted as a prediction of future average lifetime.

Expected lifetime is conventionally calculated separately for males and females, and is one of the results of a (mortality or actuarial or population) life table analysis. This type of analysis uses age-specific death rates calculated from age-specific population sizes and numbers of deaths. Hence life tables are usually calculated for census years only since accurate estimates of population sizes are required. Mortality data pertinent to the three consecutive years centred on and encompassing the census year are averaged in an attempt to smooth out random fluctuations in the observed numbers of deaths. The study of population mortality patterns is generally acknowledged as beginning with Graunt (1662), and subsequently the methodology of the life table has evolved to become a basic tool of demographers (*eg* Newell 1988) and actuaries (*eg* Benjamin & Haycocks 1970). There are many standard statistical texts covering the methodology of life table analysis (*eg* Elandt-Johnson & Johnson 1980).

Very few official life tables and hence estimates of expected lifetime have been produced for South Australia. Invariably 19th century references to Australian mortality are based on New South Wales or Victorian data (Pell 1867, BurrIDGE 1884). Some official South Australian life tables have been calculated for the period 1881–1910, but these tables were calculated from mortality data of ten-year periods. This methodology was discarded when the Commonwealth Statistician (Wilson 1936) decided to cease publication of separate life tables for each Australian State on the basis of the “.. time (thus) saved..”. In the 1970’s the Australian Bureau of Statistics recommenced producing life tables specifically for each State. Thus the complete mortality experience of South Australia, as measured by male and female expected lifetimes, has not been consistently or comprehensively investigated.

Materials and Methods

The results presented in this paper have been extracted from a thesis presented for an MSc degree at The University of Adelaide, Leppard (2003). The thesis can be accessed electronically at <http://thesis.library.adelaide.edu.au/public/adt-SUA20030422.122816/>.

A very brief overview of the material covered in the thesis is given here.

The essential data requirements to calculate a life table for a given census year are, first, the population size at each single year of age; and second, the number of deaths at each single year of age for that census year, and for the calendar years immediately preceding and following it. Population data were obtained from official sources for each of the 25 censuses carried out in South Australia since 1841: 12 colonial censuses and 13 post-Federation censuses. Sources for these data include the South

School of Mathematical Sciences, University of Adelaide, Adelaide, South Australia, 5005, Australia. Email: pleppard@maths.adelaide.edu.au.

Australian Parliamentary papers, the *SA Government Gazette*, the *Statistical Register of South Australia (1850-1975)*, and various publications of the Commonwealth Bureau of Census and Statistics and its successor organisation, the Australian Bureau of Statistics. Age-specific numbers of deaths by sex are also available from these same sources, although the published data for the years 1841 to 1860 are in a statistically limiting form principally because of various types of grouping by age of the data. This deficiency of the official records has been overcome by tabulating the primary data contained in death certificates lodged with the Registry of Births, Deaths and Marriages, which are held in the archives of State Records of South Australia. Permission was obtained from the Registrar for access to the Registry's records, and approximately 18,000 death certificates for relevant years of the above period were examined and the deaths they reported were classified according to year, sex and age at death. Indexes to the burial records of Holy Trinity church and the West Terrace cemetery were used to obtain data from which the age-specific number of deaths was estimated for each sex for 1840. It is impossible to provide within the space limitations of this paper a comprehensive description of the characteristics of all data sets that have been used to calculate expected lifetime. The reader is referred to Leppard *loc cit* for a detailed description for each census year of the process of data collection, a discussion of the limitations of the data, estimates of expected lifetime calculated by the life table method, and estimates of sampling error calculated by using the computationally intensive statistical bootstrap procedure (Efron & Tibshirani 1993). For each census year a robustness analysis is also presented, where an examination is made of the effect on expected lifetime of under-reporting in the age-specific population sizes and number of deaths. All data files and computer programs can be publicly accessed from the web site previously indicated.

Expected lifetime is calculated here in the following way, conventionally for males and females separately. Let ${}_1p_0$ be the number of individuals aged between 0 and 1 years at a census. Let ${}_1d_0$ be the average number of individuals who died between the ages of 0 and 1 years, determined from the number of deaths registered in the census year and the years immediately preceding and following the census year. Then the quantity ${}_1q_0$ is calculated from ${}_1p_0$ and ${}_1d_0$ as

$${}_1q_0 = \frac{{}_1d_0}{{}_1p_0 + \frac{1}{2}{}_1d_0}$$

It is sometimes recommended that, in circumstances where extremely high infant mortality prevails, a factor smaller than the factor

of $\frac{1}{2}$ should be used in the calculation of ${}_1q_0$. This has not been done in the calculation of expected lifetimes shown in Table 1, and consequently some of the values given there for the 19th century may be slightly larger than perhaps they otherwise would be. Newell *loc cit* suggests that a factor of .3 be used instead of $\frac{1}{2}$ for "developing countries". Recalculation of expected lifetime for selected census years for South Australia using this value for the factor has produced small differences that are less than the standard error of the expected lifetime.

In an analogous manner, ${}_1q_1$ is calculated for age group 1-2 years, ${}_1q_2$ for age group 2-3 years, and so on, for each yearly age group. Thus using standard demographic notation, ${}_1q_j$ is a mortality rate specific to the group aged between j years and $(j+1)$ years.

A distribution function for lifetime values, F , is defined with this set of q -values as

$$F(x) = 1 - (1 - {}_1q_0)(1 - {}_1q_1)(1 - {}_1q_2) \dots (1 - {}_1q_{x-1})$$

for $x = 1, 2, 3, \dots$, where $F(0) = 0$ and here $F(105) = 1$ by definition. Expected lifetime is calculated from the tabular values of F by the trapezoidal method of numerical integration.

It should be noted that neither F nor expected lifetime is directly applicable to the population of individuals in the census year from which the q -values are determined. They are concepts that prospectively apply to a hypothetical population of infants born in the census year, if it is assumed that the currently prevailing mortality rates, as measured by the q -values, eventuate for these infants throughout their lifetimes. There are mathematical arguments that suggest that expected lifetime is an underestimate of the unrealised average lifetime of this hypothesised population of infants.

The potential effect of under-counting is examined in the following way. Population sizes are obtained following a census, and the numbers of deaths are compiled from the death certificates required by law. Both of these processes are not necessarily exact and some individuals could be excluded. Consider ${}_1p_0$ and ${}_1d_0$ which are used to calculate ${}_1q_0$, and suppose the "correct" values of these two quantities are larger by factors of O_1 and O_2 respectively. Then the "correct" value of ${}_1q_0$ would be

$${}_1q_0(\text{"correct"}) = \frac{O_1 {}_1d_0}{O_1 {}_1p_0 + \frac{1}{2} O_2 {}_1d_0} = \frac{{}_1d_0}{\frac{O_1}{O_2} {}_1p_0 + \frac{1}{2} {}_1d_0}$$

which is close to ${}_1q_0$ calculated by using the supposedly under-counted values ${}_1p_0$ and ${}_1d_0$ if $\frac{O_1}{O_2} \approx 1$; that is, ${}_1q_0$ is an appropriate substitute for ${}_1q_0$ ("correct") if the extent of under-counting is

approximately the same for both the population size and the number of deaths. For each census year and sex, expected lifetimes are given in Leppard *loc cit* for combinations of assumed levels of under-counting in both population size and numbers of deaths.

Results and Discussion

Estimates of expected lifetime (EL) for South Australian males and females for 1841-1996 are shown in Table 1. A standard error, SE (EL), is also given for each estimate. Table 1 also shows the total population size and the average total number of deaths on which each estimate is based.

The estimates of expected lifetime are also displayed graphically in Figure 1, which is annotated to indicate

1. The first census at which the estimate of expected lifetime for females can be statistically claimed to be significantly greater than the estimate for males.
2. The passing of the first South Australian Public Health Act, as a response to the deterioration of social and public health conditions in the 1860's and 1870's. The effect of this deterioration on population mortality is shown by the disruption

over this period in the generally increasing sequence of expected lifetime values.

3. Larger time intervals between successive estimates of expected lifetime as a consequence of the postponement of censuses during the Great Depression and World War II.

The estimates of expected lifetime presented in Table 1 and Figure 1 have been derived from data from populations that have evolved from the initial British settlement of South Australia with subsequent migration from Western and Southern Europe. These estimates have been derived primarily from routinely recorded official population and mortality data from which Aborigines were excluded because of a government policy that remained in force until the second half of the 20th century.

The two series of expected lifetimes that are presented here are the most extensive and comprehensive available for any Australian state or for the Commonwealth, with all estimates consistently calculated using a currently accepted standard methodology. The results delineate for the first time the changes in mortality that have occurred in South Australia over 150 years of European settlement. The electronic provision of the basic data files through the previously stated web address has been made to assist demographic researchers.

TABLE 1. *Expected lifetime with standard error for South Australia 1841-1996.*

Census	Population	Male			Population	Female		
		Deaths	EL	SE(EL)		Deaths	EL	SE(EL)
1841	8195	140	44.27	2.59	6345	102	48.17	1.88
1844	9525	172	41.95	1.56	7608	128	43.49	1.60
1846	12670	236	41.57	1.55	9650	163	46.67	2.08
1851	35309	544	45.73	1.24	27730	439	47.62	1.31
1855	43716	713	47.68	1.27	41470	620	50.00	1.27
1861	64640	1111	48.55	1.06	61678	951	51.88	1.20
1866	85625	1434	47.39	0.86	77975	1178	50.34	0.88
1871	95288	1438	48.69	0.67	90164	1165	52.19	0.77
1876	110410	1972	43.57	0.58	102734	1659	46.09	0.64
1881	149530	2283	47.62	0.50	130335	1819	50.76	0.62
1891	166801	2156	52.52	0.47	153630	1787	54.98	0.52
1901	184424	2169	54.56	0.47	178182	1821	57.72	0.50
1911	207358	2269	58.81	0.41	201200	1880	62.41	0.42
1921	248267	2663	60.01	0.38	246893	2221	63.53	0.39
1933	290429	2701	65.34	0.34	289546	2386	68.04	0.35
1947	320031	3478	67.17	0.27	326042	2995	71.28	0.26
1954	403903	3958	67.72	0.25	393191	3267	73.07	0.24
1961	490225	4412	68.62	0.22	479115	3537	74.91	0.21
1966	548530	5030	68.57	0.21	543344	4034	75.22	0.20
1971	586451	5454	68.67	0.20	587656	4408	75.58	0.20
1976	619759	5402	70.06	0.19	624595	4488	76.93	0.18
1981	635695	5473	71.49	0.19	649467	4438	78.92	0.18
1986	666159	5626	72.98	0.18	679985	4824	79.48	0.18
1991	690805	5856	74.08	0.17	709802	5156	80.30	0.17
1996	698799	5989	75.33	0.17	722673	5504	81.34	0.16

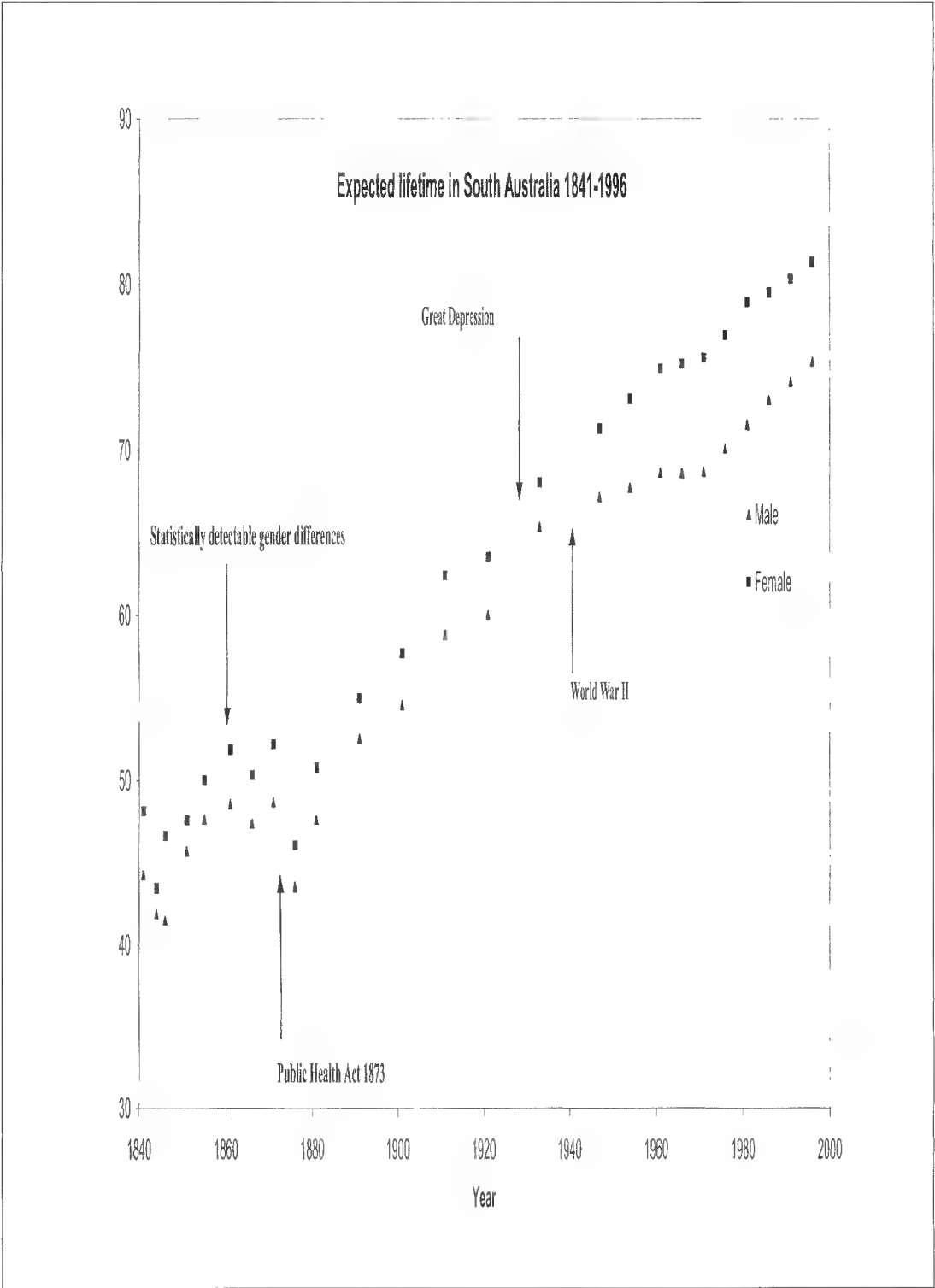


Fig. 1. Expected lifetime in South Australia 1841-1996.

TABLE 2. *Comparison of expected lifetime for males.*

	SA	Other Sources	Australia (6)	Britain (7)	US (8)
1841	44.27			40.2	
1855	47.68				
1838-1854				39.9	
1856-1861		45.58 (1)			
1861	48.55				
1871	48.69				
1870-1881		46.47 (2)			
1881	47.62				
1881-1890		50.61 (3)	47.20	43.7	
1891	52.52				
1891-1900		53.02 (3)	51.08	44.1	
1901	54.56				48.0
1901-1910		56.76 (3)	55.20	48.5	
1911	58.81				
1933	65.34		63.48	58.7	62.7
1954	67.72	67.82 (4)	67.14		67.5
1976	70.06	70.27 (5)	69.56	69.9	69.9
1996	75.33	75.30 (5)	75.70	74.5	73.9

(1) Pell loc cit (NSW).

(2) Burrige loc cit (composite states, excludes SA).

(3) Commonwealth Census 1911, Vol 3. (SA).

(4) Wickens, Australian Journal of Statistics, 2, 1960. (SA).

(5) Deaths SA, Australian Bureau of Statistics.

(6) Australian Life Tables, Australian Government Actuary.

(7) English Life Tables, UK Government Actuary's Office. (England & Wales).

(8) US National Vital Statistics Reports, Vol 51, 3, 2002.

TABLE 3. *Comparison of expected lifetime for females.*

	SA	Other Sources	Australia	Britain	US
1841	48.17			42.2	
1855	50.00				
1838-1854				41.9	
1856-1861		45.58			
1861	51.88				
1871	52.19				
1870-1881		49.64			
1881	50.76				
1881-1890		53.81	50.84	47.2	
1891	54.98				
1891-1900		56.10	54.76	47.8	
1901	57.72				51.0
1901-1910		60.39	58.84	52.4	
1911	62.41				
1933	68.04		67.14	62.9	66.3
1954	73.07	73.09	72.75		73.7
1976	76.93	77.24	76.56	76.0	77.5
1996	81.34	81.34	81.40	79.6	79.7

A selection of expected lifetimes presented here for South Australia in Table 1 are shown in Table 2 and Table 3 (column SA) for comparison with other estimates and other similar populations; with estimates for other colonies and for South Australia, by other authors (Other sources); with Australia, by the Australian Bureau of Statistics and by the Australian Actuary; with Britain, by the Government Actuary's Office; and with the United States, by the

National Vital Statistics Office.

Generally, expected lifetimes for South Australia have compared more than favourably with the other estimates until the first third of the 20th century, after which time there has been a gradual lessening of the differences between expected lifetimes. This most probably reflects the effect of globalisation and standardisation in conditions of Western industrial societies.

References

- BENJAMIN, B. & H. W. HAYCOCKS (1970). *The Analysis of Mortality and other Actuarial Statistics*. Cambridge, Cambridge University Press.
- BURRIDGE, A. F. (1884). "On the rates of mortality in Australia." *Journal of the Institute of Actuaries* **24**: 333-358.
- EFRON, B. & R. J. TIBSHIRANI (1993). *An Introduction to the Bootstrap*. New York, Chapman & Hall.
- ELANDT-JOHNSON, R. C. & N. L. JOHNSON (1980). *Survival Models and Data Analysis*. New York, John Wiley & Sons.
- GRAUNT, J. (1662). *Natural and political observations made upon the bills of mortality* (reprinted 1939). Baltimore, Johns Hopkins Press.
- LEPPARD, P. I. (2003). *An analysis of population lifetime data for South Australia, 1841- 1996*. MSc (Statistics) thesis, School of Applied Mathematics, The University of Adelaide <http://thesis.library.adelaide.edu.au/public/adt-SUA20030422.122816/>.
- NEWELL, C. (1988). *Methods and Models in Demography*. London, Belhaven Press.
- PILL, M. B. (1867). "On the rates of mortality and expectation of life in New South Wales as compared with England and other countries." *Transactions of the Royal Society of New South Wales* **1**: 66-76.
- WILSON, R. (1936). *Official year book of the Commonwealth of Australia*, Commonwealth Bureau of Census and Statistics, Canberra.

VARIATION IN SEX RATIOS IN FOUR ANGUINA (NEMATODA: ANGUINIDAE) SPECIES

By I. T. RILEY & T. BERTOZZI†*

Summary

Riley, I. T. & Bertozzi T. (2000). Variation in sex ratios in four Anguina (Nematoda: Anguinidae) species. Trans. R. Soc. S. Aust. 128(1), 43-46, 31 May, 2004.

Number and ratios of adult male and females nematodes in four Anguina species. *A. australis* from *Ehrharta longiflora*, *A. funesta* from *Lolium rigidum*, *A. microlaenae* from *Microlaena stipoides* and an undescribed species from *Polypogon monspeliensis*, were determined and analysed. The sex ratio in *A. australis* and *A. funesta* differed statistically from the expected 1:1, with 57% and 56% females, respectively. The ratios for *A. microlaenae* and *Angina* sp. ex *Polypogon* conformed to the expected 1:1. Galls initiated by single sex nematodes, both male and female, were found in the four species, except that no galls containing only males were found in *A. australis*. Reproduction in this group appears to be amphimictic, as single sex galls contained no progeny and the data point to the possibility of a mechanism that favours female occupancy of galls.

Key Words: *Anguina australis*, *Anguina funesta*, *Anguina microlaenae*, seed gall nematode, leaf gall nematode, gall initiation, sex ratios, reproduction, amphimixis.

VARIATION IN SEX RATIOS IN FOUR *ANGUINA* (NEMATODA: ANGUINIDAE) SPECIES.

by I. T. RILEY* & T. BERTOZZI†

Summary

RILEY I. T. & BERTOZZI T. (2000). Variation in sex ratios in four *Anguina* (Nematoda: Anguinidae) species. *Trans. R. Soc. S. Aust.* **128**(1), 43–46, 31 May, 2004.

Number and ratios of adult male and females nematodes in four *Anguina* species, *A. australis* from *Ehrharta longiflora*, *A. funesta* from *Lolium rigidum*, *A. microlaenae* from *Microlaena stipoides* and an undescribed species from *Polypogon monspeliensis*, were determined and analysed. The sex ratio in *A. australis* and *A. funesta* differed statistically from the expected 1:1, with 57% and 56% females, respectively. The ratios for *A. microlaenae* and *Angina* sp. ex *Polypogon* conformed to the expected 1:1. Galls initiated by single sex nematodes, both male and female, were found in the four species, except that no galls containing only males were found in *A. australis*. Reproduction in this group appears to be amphimictic, as single sex galls contained no progeny and the data point to the possibility of a mechanism that favours female occupancy of galls.

KEY WORDS: *Anguina australis*, *Anguina funesta*, *Anguina microlaenae*, seed gall nematode, leaf gall nematode, gall initiation, sex ratios, reproduction, amphimixis.

Introduction

Species of the nematode genus *Anguina* form galls in plants, mostly in poaceous hosts. The type species, *Anguina tritici*, is considered to reproduce by amphimixis (Triantaphyllou and Hirschmann 1966). Galls are initiated by invasive stage juveniles (usually J2s), which, confined to the gall, develop to adults. So, mates can only be found amongst the relatively small number of individuals present in the gall. Therefore, a mechanism to increase the likelihood of both females and males occurring in individual galls would be advantageous. The mechanism would need to operate before or during gall initiation, unless sex in *Anguina* spp. can be environmentally determined.

In two species, *Anguina australis* and *Anguina microlaenae*, most galls contain only small numbers of adults, with some galls containing only females (Riley *et al.* 2001; de Silva and Riley 2002). It was suggested that this may indicate a mechanism whereby only genetically female juveniles could initiate galls or that sex was environmentally determined (de Silva and Riley 2002). In both cases, no progeny were found in the single sex galls, so there was no evidence of parthenogenetic reproduction.

As sex ratios and adult populations in galls for only two leaf-gall forming species of the genus have been examined in detail, similar data were collected for two seed-gall forming species, *Anguina funesta* and

Anguina sp. ex *Polypogon monspeliensis* and further data for *A. microlaenae*. These data were examined for further evidence of mechanisms that determine sex ratios and first generation populations in *Anguina* galls.

Materials and Methods

Anguina australis. Data on sex of *A. australis* adults in galls in *Ehrharta longiflora* came from a published study (Riley *et al.* 2001)

Anguina funesta. *Lolium rigidum* plants were grown (about 100 plants per pot) in a peat/sand mix (UC mix; Baker 1957) in 280 mm pots outdoors at Urrbrae, South Australia. Seed and nematode galls (about 100 per pot) were applied early in July 2001 and inflorescences harvested for collection of galls in late October 2001. Ten inflorescences were dissected and 203 galls collected. Gall positions (spikelet and floret) were recorded. Each gall was opened in water under a dissecting microscope to release and count adult female and male nematodes. The presence of eggs and juveniles was noted.

Anguina microlaenae. A further eighty galls from each of two populations of *Microlaena stipoides* from Toowoomba, Queensland were assessed as for the *A. funesta* galls from *L. rigidum* and combined with data previously obtained from these populations (de Silva and Riley 2002).

Anguina sp. ex *Polypogon*. *Anguina* sp. galls from *Polypogon monspeliensis* were obtained from plants collected in 1992 and 1993 from two sites in south-eastern South Australia. Galls in these plants had formed in primary shoot meristems, pedicel meristems and ovaries and in this report are termed apical, pedicel and seed galls respectively. A total of

* Plant and Pest Science, School of Agriculture and Wine, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia. Email: ian.riley@adelaide.edu.au.

† Evolutionary Biology Unit, South Australian Museum, North Terrace, Adelaide South Australia 5000, Australia.

TABLE 1. *Gall types, sex and ratio of adults for populations of four Anguina species.*

	<i>A. australis</i> *	<i>A. funesta</i>	<i>A. microlaenae</i> **	<i>Anguina</i> sp. ex <i>Polypogon</i>			
Gall type	Leaf	Seed	Leaf	Apical	Seed	Pedice	Total
Number examined	194	203	199	95	122	14	232
Females							
Range	1-5	0-13	0-6	0-7	0-8	1-3	0-8
Mean \pm SE	1.68 \pm 0.07	2.66 \pm 0.14	1.65 \pm 0.08	1.74 \pm 0.14	1.39 \pm 0.08	1.64 \pm 0.23	1.55 \pm 0.07
Median	1	2	1	1	1	1	1
Males							
Range	0-3	0-9	0-8	0-8	0-11	0-3	0-11
Mean \pm SE	1.96 \pm 0.04	1.98 \pm 0.10	1.75 \pm 0.10	1.90 \pm 0.18	1.37 \pm 0.10	1.21 \pm 0.19	1.58 \pm 0.09
Median	1	2	1	1	1	1	1
Adults							
Range	1-7	1-19	0-12	1-15	1-19	2-5	1-19
Mean \pm SE	2.88 \pm 0.08	4.64 \pm 0.22	3.40 \pm 0.15	3.63 \pm 0.29	2.75 \pm 0.17	2.86 \pm 0.33	3.12 \pm 0.15
Median	3	4	3	2	2	2	2
Proportion female							
Range	0.33-1	0-1	0-1	0-1	0-1	0.4-1	0-1
Mean \pm SE	0.573 \pm 0.009	0.556 \pm 0.011	0.504 \pm 0.014	0.497 \pm 0.016	0.504 \pm 0.011	0.567 \pm 0.039	0.505 \pm 0.009
Median	0.50	0.57	0.50	0.50	0.50	0.50	0.5

*Data from Riley *et al.* (2001)

**Data from de Silva and Riley (2002) combined with further data collected on the same population

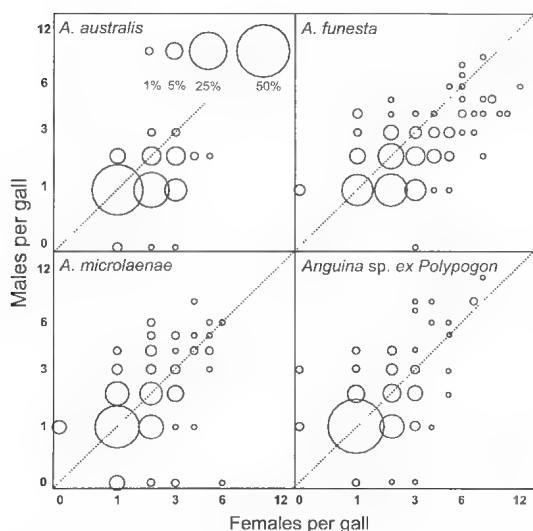


Fig. 1. Proportion of galls formed by four *Anguina* spp. with various combinations adult nematodes (dotted line represents 1:1, area of the circle represents the proportion of the population at each combination and scale indicated by circles labelled 1, 5, 25 and 50%.)

232 galls were assessed consisting of 95 apical, 122 seed and 14 pedicel galls. Galls were dissected and adults counted, as above.

GENSTAT 5 (Lawes Agricultural Trust, Rothamsted Experimental Station) was used to run statistical analyses.

Results

Table 1 gives details of the adults in the galls of each of the four nematode species. Infestation of the *Lolium rigidum* was heavy, nearly all florets in the spikelets examined containing galls. The contents of the galls from the two populations of *A. microlaenae* did not differ statistically and were combined. Differences between the three classes of gall produced by *Anguina* sp. in *P. monspeliensis* could not be reliably tested because of inequality of variance and no variance-stabilizing transformation was effective, so they are presented individually and as a total. Two galls with exceptionally large numbers of adults, one gall formed by *A. microlaenae* with 1 female and 38 males and one apical gall formed by *Anguina* sp. in *P. monspeliensis* with 24 females and 31 males, were excluded from analysis as aberrant.

The sex ratio for each species was tested for the whole sample by chi-square test (Table 2). The numbers of females per male in galls formed by both *A. australis* and *A. funesta* were greater than the expected ratio of 1:1. This was consistent with the mean proportion of females found in the galls of both species (Table 1) being more than half. The ratio for *A. microlaenae* and *Anguina* sp. ex *Polypogon* did not differ statistically from the expected 1:1. Despite the divergence of the sex ratio from 1:1 in two species, the only species with a median proportion of females that differed from this ratio was *A. funesta* with a median of 0.57 (i.e. 1.33:1).

The proportion of galls with each combination of

TABLE 2. Chi-squared test of conformity of *Anguina* sex ratios to an expected 1:1.

<i>Anguina</i> sp.	Observed ratio (female/male)	Chi-squared (df = 1)	Probability
<i>A. australis</i>	1.41	15.91	< 0.001
<i>A. funesta</i>	1.36	22.01	< 0.001
<i>A. microlaenae</i>	0.95	0.53	0.47
<i>A. sp. ex Polypogon</i>	0.98	0.07	0.79

adults for the four species is shown in Figure 1. The bias in female occupancy of galls can be seen for *A. australis* and *A. funesta* with 40% and 51% of galls having more females than males, respectively. By comparison, only 25% and 19% of *A. microlaenae* and *Anguina* sp. ex *Polypogon* galls had more females than males.

Galls occupied by single adult males and females were found in the four nematode species except that no galls containing only males were found for *A. australis*. The greatest proportion of single sex galls was found for *A. microlaenae* (10%). No eggs or juveniles were found in any single sex gall.

Analysis of gall position (spikelet and floret) for *A. funesta* in relation to numbers of adults and progeny and sex ratio revealed only one significant relationship (data not shown). A significant regression ($P < 0.001$) was found between sex ratio and spikelet (the latter being the independent variable). The lower the position of the spikelet in the inflorescence the greater proportion of females in the galls. However, only about 6% of the variation in sex ratio was attributable to spikelet position. No effect of floret position within the spikelet was found.

Discussion

Reproduction in the species examined appears to be exclusively amphimictic, as no progeny were found in galls containing single adults. The sex ratio of 1:1 found in *A. microlaenae* and *Anguina* sp. ex *Polypogon* is consistent with amphimictic reproduction. However, the overall sex ratio of about 1.4 females/male for *A. australis* and *A. funesta* points to the existence of mechanism that controls the sex of adults in galls.

The data arising from the earlier, more limited, examination of *A. microlaenae* galls and the *A. australis* galls led to postulation (de Silva and Riley 2002), based on single adults in galls being only female, that galls might only be initiated by genetically female juveniles or that environmental sex determination was involved. The additional

data presented here revealed that galls formed by single males occur in three of the species, including *A. microlaenae* and provide no support for either proposition.

Therefore, the significantly higher number of females in *A. australis* and *A. funesta* points to a possible mechanism involving relative rather than absolute differences in behaviour between the sexes. Although both sexes can initiate galls, female occupancy is quantitatively more likely. Given that host invasion and gall initiation rates were high in the *L. rigidum* examined (mean of 4.6 adults per gall compared to 2.2 to 2.6 in field populations, McKay *et al.* 1981), it is possible that such a mechanism operates to maximise potential reproduction of the species when there is more competition for gall sites. This cannot be tested from the data obtained, as they were not derived from a controlled experiment. However, the tendency for more females in the lower galls in *L. rigidum* might be consistent with this proposal, if there was more competition for sites at the time these galls were formed. Chit¹ also found that galls formed by *Mesoanguina mobilis* in *Arctotheca calendula* had 2 to 7 first generation adults, most commonly with 3 females and 2 males, thus supporting a mechanism to favour females occurring more broadly in anguinid genera.

A consistent pattern in the data is the low frequency of galls containing only single adults for all species and a strong bias towards galls containing two adults (one female and one male), in three species. It is possible that galls initiated by single nematodes largely fail to mature and or that gall initiation is favoured by the combined efforts of multiple juveniles. Juveniles must secrete plant growth regulators to induce galls, so it is possible that single juveniles might have difficulty achieving a critical concentration to effect the necessary change in the plant. The approximate balance of male and females in most galls also points to mechanism other than chance.

The occurrence of galls containing multiple and variable numbers of adults in all species indicates that this process is not tightly regulated and must be to some degree a function of number of nematodes that invade the plant relative to the

¹ Chit, W. (1971) "Biology of *Anguina mobilis* n. sp. on capeweed (*Cryptostemma calendulaceum*)" PhD thesis, The University of Adelaide (Unpubl.).

number of potential gall sites. Examining gall occupancy under a range of inoculation levels could provide more evidence of the underlying pattern.

Acknowledgments

Tony Debicki helped with the culture *A. funesta* in *L.*

rigidum. Drs K. Owen and P. Williamson provided infested *M. stipoides* from Toowoomba. Ms M. Lorimer provided statistical advice. I. Riley's position is in part funded by the Grains Research and Development Corporation. During the period the *P. monspeliensis* galls were collected, T. Bertozzi was supported by the Australian Meat and Livestock Corporation.

References

- BAKER, K. F. (1957). The U.C. system for producing healthy container-grown plants through the use of clean soil, clean stock and sanitation. California Agricultural Experiment Station Manual 23 (University of California, Berkeley, USA.).
- DE SILVA, P. & RILEY, I. T. (2002). Aspects of the survival and reproduction of *Anguina microlaenae* (Nematoda: Anguinidae). *Trans. R. Soc. S. Aust.* **126**: 45-49.
- McKAY, A. C., FISHER, J. M. & DUBÉ A. J. (1981). Ecological field studies on *Anguina funesta*, the vector in annual ryegrass toxicity. *Australian Journal of Agricultural Research* **32**, 917-926.
- RILEY, I. T., SCHMITZ, A. & DE SILVA, P. (2001). *Anguina australis*, a vector for *Rathayibacter toxicus* in *Ehrharta longiflora*. *Australasian Plant Pathology* **30**, 361-364.
- TRANTAPHYLLOU, A. C. & HIRSCHMANN, H. (1966). Gametogenesis and reproduction in the wheat nematode, *Anguina tritici*. *Nematologica* **12**, 437-442.

**SYPHACIA (SYPHACIA) AUSTRALASIENSIS SP. NOV.
(NEMATODA: OXYURIDAE) FROM RATTUS LEUCOPUS
(MURIDAE) FROM PAPUA NEW GUINEA AND AUSTRALIA**

*By L. R. SMALES**

Summary

Smales, L. R. (200) Syphacia (Syphacia) australasiensis sp. nov. (Nematoda: Oxyuridae) from Rattus leucopus (Muridae) from Papua New Guinea and Australia. Trans. R. Soc. S. Aust. 128(1), 47-51, 31 May, 2004.

Syphacia (Syphacia) australasiensis sp. nov. is described from the caecum of Rattus leucopus (Gray) (Rodentia: Muridae) from Papua New Guinea and Queensland, Australia. The new species is distinguished from congeners with an oval cephalic plateau by the lack of lateral alae, a longitudinal ridge along the egg and a combination of measurements including spicule length, tail length, distance to anterior mamelon and size of eggs. The origins of the genus and the relationships of the species in the Australian region are discussed.

Key Words: Nematoda, Muridae, Rattus, Syphacia, new species.

***SYPHACIA (SYPHACIA) AUSTRALASIENSIS* SP. NOV. (NEMATODA: OXYURIDAE)
FROM *RATTUS LEUCOPUS* (MURIDAE) FROM PAPUA NEW GUINEA
AND AUSTRALIA**

by L. R. SMALES*

Summary

SMALES, L.R. (2004) *Syphacia (Syphacia) australasiensis* sp. nov. (Nematoda: Oxyuridae) from *Rattus leucopus* (Muridae) from Papua New Guinea and Australia. *Trans. R. Soc. S. Aust.* 128(1), 47-51, 31 May, 2004.

Syphacia (Syphacia) australasiensis sp. nov. is described from the caecum of *Rattus leucopus* (Gray) (Rodentia: Muridae) from Papua New Guinea and Queensland, Australia. The new species is distinguished from congeners with an oval cephalic plateau by the lack of lateral alae, a longitudinal ridge along the egg and a combination of measurements including spicule length, tail length, distance to anterior mamelon and size of eggs. The origins of the genus and the relationships of the species in the Australian region are discussed.

KEY WORDS: Nematoda, Muridae, *Rattus*, *Syphacia*, new species.

Introduction

The pin worm genus *Syphacia* (Nematoda: Oxyuridae) is a cosmopolitan genus occurring in the rodent families Cricetidae and Muridae (Hugot 1988). All Australian rodents are contained within the family Muridae, either a few relatively recent arrivals, representative of the genus *Rattus* (Murinae), or, the majority of species (Hydromyinae), that arrived in Australia from Indonesia via New Guinea no more than 5-8 million years ago (Strahan 1995). The currently known pin worm species associated with the murids from Australia and the island of New Guinea are *Syphacia muris* Yamaguti, 1935, a cosmopolitan species; *Syphacia darwini* Quentin & Hugot, 1988 known only from Australian representatives of the hydromyine genus *Melomys* and *Syphacia longaecausta* Smales, 2001 known only from New Guinean representatives of the genus *Melomys*.

Rattus leucopus (Gray) the Cape York rat is one of only six species of murids that occur in both Australia and Papua New Guinea (Flannery 1995; Strahan 1995). Examination of material collected from both locations revealed a new species of *Syphacia* that is described in this paper.

Materials and Methods

Nematodes, previously dissected from *R. leucopus* and stored in 70% ethanol in the South Australian Museum (SAM) or the CSIRO Wildlife Collection, Canberra (CSIRO), were cleared in lactophenol for examination. Specimens identified as *Syphacia* sp.

were measured using an ocular micrometer and drawn with the aid of a drawing tube attached to an Olympus BH microscope. Measurements for 10 individuals of each sex are presented in μm as the range followed by the mean in parentheses.

***Syphacia (Syphacia) australasiensis*
(FIGS 1-11)**

Holotype

♂ from caecum of *Rattus leucopus* (Gray) Brown River, Papua New Guinea, 25.vi.1968 coll. W. Ewers, SAM AHC 32142.

Allotype

♀ same data SAM AHC 32143.

Paratypes

Same data SAM AHC 5141.

Other material examined

From caecum of *Rattus leucopus*, E. McIlwraith Ra., Cape York Peninsula, North Queensland, Australia 10.viii.1990, coll. P. Catling and P. Haycock, CSIRO N3325, 5 ♀♀, 3 ♂♂; Brown River, Papua New Guinea, 25.vi.1968, coll. W. Ewers, AM AHC 5201, 5152, 5149, 95 ♀♀, 1 ♂.

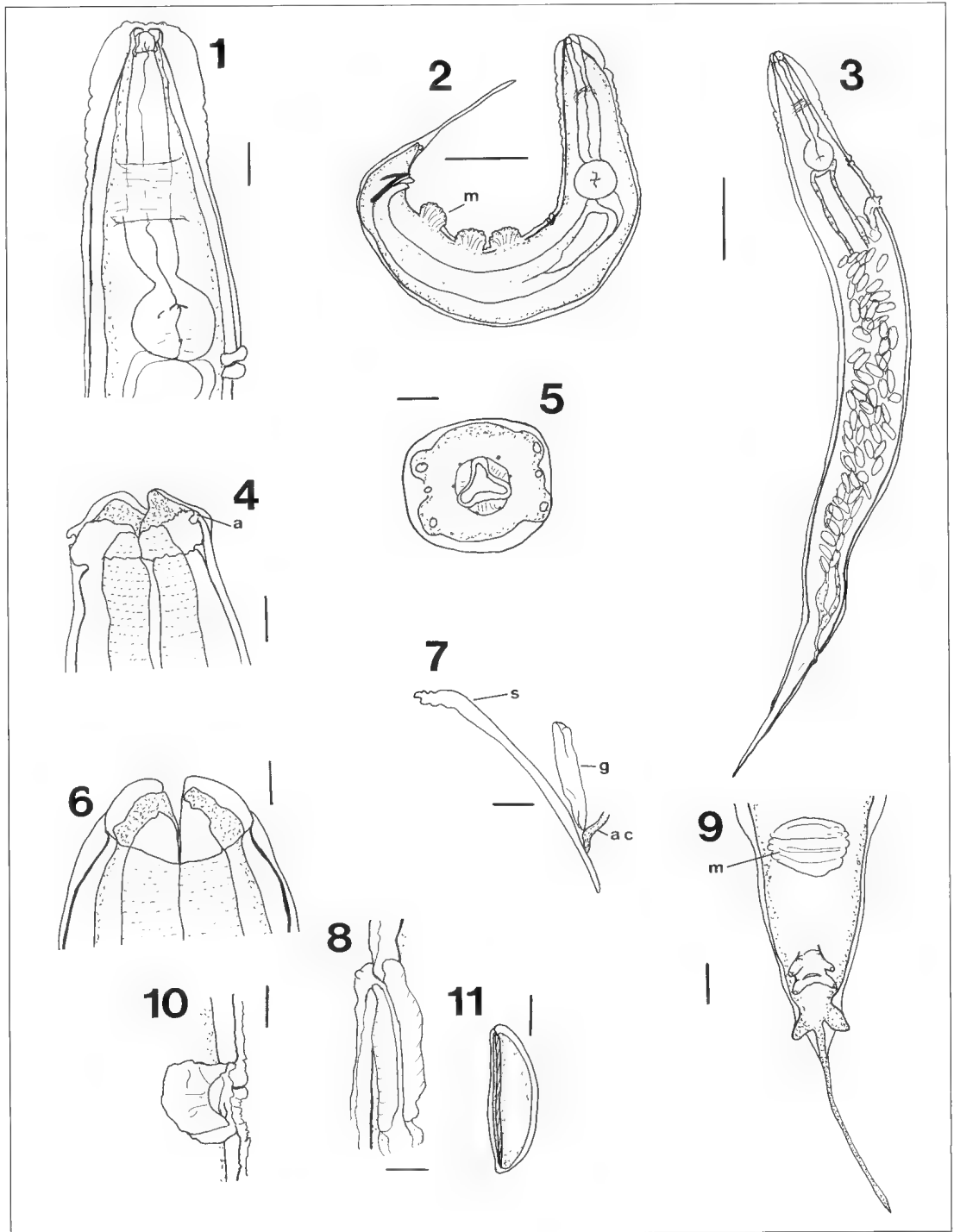
Site in host

Caecum and colon.

Description

Small nematodes, typical oxyurid shape, with transverse cuticular striations. Cephalic inflation distinct. Cephalic plateau oval, elongated laterally; distance between amphids 30, amphids situated between cephalic papillae; cephalic papillae on lateral projections; six labial papillae; mouth

* School of Biological and Environmental Sciences, Central Queensland University, Rockhampton Qld 4702, Australia.
Email: l.warner@cqu.edu.au



Figs 1-11 *Syphacia (Syphacia) australasiensis* sp. nov. 1. Male, anterior end, dorso-ventral view. 2. Male, lateral view. 3. Female, lateral view. 4. Anterior end, optical section, dorso-ventral view. 5. En face view. 6. Anterior end, optical section, lateral view. 7. Spicule and gubernaculum, lateral view. 8. Vagina, lateral view. 9. Male, posterior end, ventral view. 10. Excretory pore, lateral view. 11. Egg. Scale bars 1, 8, 9, 10, 11 25µm; 2, 50µm; 3, 100µm; 4, 5, 6, 7, 10µm.

opening simple, three small distinct pseudolabia. Oesophagus with isthmus, terminating in spherical bulb. Excretory pore posterior to oesophageal bulb. Nerve ring surrounding anterior oesophagus. Deirids not seen. Alae absent.

Male

Total length 690 – 1250 (810), maximum width 80 – 102 (95). Oesophagus 142 – 208 (192) long, oesophageal bulb 46 – 55 (51) in diameter. Nerve ring 75 – 120 (94), excretory pore 228 – 462 (289) from anterior end. Three mamelons with prominent annulations, spines not observed; first mamelon 297

583 from anterior end, second mamelon close behind first, third mamelon close behind second; mamelons all 35 – 40 long. Tail 142 – 181 (155) long. Spicule needle shaped 61 – 68 (65) long; gubernaculum 29 – 36 (31) long, ventral barb not observed. Two pairs preanal, one pair large post anal caudal papillae.

Female

Total length 1900 – 2900 (2400), maximum width 160 – 268 (170). Oesophagus 187 – 355 (298) long, oesophageal bulb 73 – 82.5 (78) in diameter. Nerve ring 107 – 135 (122), excretory pore 315 – 570 (460). Vulva with prominent knob, 436 – 804 (655) from anterior end. Tail 335 – 436 (385) long. Eggs with longitudinal ridge, 82.5 – 95 (87.5) by 29.5 (36.3) (33).

Etymology

The species is named to reflect that it is found in both Papua New Guinea and Queensland.

Discussion

The nematode species described above belongs to the genus *Syphacia* Seurat, 1916 because it possesses the suite of characters proposed by Hugot (1988, see also figs 23, 24 and 39) to distinguish the genus. It belongs within the subgenus *Syphacia* Seurat, 1916 because it has neither the rectangular cephalic plateau and well developed triangular shaped lateral alae of the subgenus *Criotoxyuris* Hugot, 1988 nor the short conical tail characteristic of the subgenus *Seuratoxyuris* Hugot, 1988. Rather, it has an oval cephalic plateau, lacks cervical alae and well developed deirids.

Syphacia (*Syphacia*) *australasiensis* n. sp. in *en face* view most clearly resembles a cluster of species from murid hosts (*Rattus* species) from the Australasian biogeographic region, namely *S. muris* Yamaguti, 1935, *S. darwini* Hugot & Quentin, 1985, *S. longaecauda* Smales, 2001 and *S. sulawesiensis* Hasegawa & Tarore, 1996. It differs from each of these species in the form of the vulva, having a

longitudinal ridge in the egg and males lacking lateral alae. It further differs from *S. muris* in having an oval rather than square cephalic plateau; from *S. longaecauda* in having a smaller cephalic plateau, 30 µm between the amphids rather than 45 – 50 µm; from *S. darwini* in having three, not two, mamelons and from *S. sulawesiensis* in having the females lacking lateral alae. *Syphacia australasiensis* differs from *S. lophuromys* Quentin, 1966 and *S. megaloon* Quentin, 1966, also lacking lateral alae in the morphology of the egg and vulva and in *en face* aspect. *S. lophuromys* and *S. megaloon* have a cephalic plateau elongated laterally with papillae and pseudolabia characterised as Group VIII by Quentin (1971). *S. lophuromys* and *S. megaloon* are found only in African murids. Further, *S. australasiensis* differs from each of the above species in one or more measurements of oesophagus, tail, spicule gubernaculum or eggs (Table 1).

The oxyurids, subfamily Syphaciinae are generally considered to have coevolutionary relationships with their hosts (Hugot, 1988). The similarities between *S. australasiensis*, *S. darwini*, *S. longaecauda* and *S. sulawesiensis* are therefore not surprising. Each has an oval cephalic plateau with distinct pseudolabia, "lips", and mouth surrounded by 6 labial papillae; each occurs in an endemic murid host, *Rattus* species or *Melomys* species; each has evolved within the Australasian biogeographic region, Sulawesi being to the east of Wallace's line, the boundary between the Asian and Australasian faunal regions (Raven, 1935).

The relationship between these four species and *S. muris* also occurring in *Rattus* species hosts, but cosmopolitan in distribution, is not clear. *Syphacia muris* is found in *R. rattus* (Linnaeus) and *R. norvegicus* (Berkenhout) (see Smales, 1997) both of which are recent arrivals in Australia. Given that Hugot & Quentin (1985) found that *S. muris* from endemic *Rattus* spp. in Australia, corresponded morphologically and morphometrically to the description from cosmopolitan *Rattus* spp., the suggestion of Hasegawa & Tarore (1996) that infections in Australian endemic murids have been acquired from the recent arrivals seems sound.

The endemic *Syphacia* species may therefore have been derived from syphaciine populations introduced into the region as their rodent hosts invaded the Island of New Guinea and then Australia (Flannery, 1995). Subsequently speciation took place in both regions. *Syphacia longaecauda* has been found only in *Melomys* spp. endemic to New Guinea while *S. darwini* is known only from *Melomys cervinipes* hosts endemic to Australia. This suggests that there has been no migration of *Melomys* between the two islands. Very few data are

available from rodent hosts from New Guinea localities however, so there may be populations of *S. darwini* present there yet to be discovered. *Rattus leucopus* occurs in both regions and in both cases harbours *S. australasiensis*. This suggests that *S. australasiensis* migrated with *R. leucopus* into Australia. More data from murids across the region is needed before relationships can be derived and

firm conclusions drawn.

Acknowledgments

Sincere thanks to Jan Forrest from the South Australian Museum and Dr. David Spratt from CSIRO Sustainable Ecosystems for lending me the material.

References

- FLANNERY, T. (1995) Mammals of New Guinea (Reed Books, Chatswood).
- HASEGAWA, H. & TARORE, D. (1996) *Syphacia* (*Syphacia*) *sulawesiensis* n. sp. and *S. (S.) muris* (Yamaguti, 1935) (Nematoda: Oxyuridae) collected from *Rattus xanthurus* (Graf, 1867) (Rodentia: Muridae) in Northern Sulawesi, Indonesia. *Trop. Zool.* **9**, 165-173.
- HUGOT, J.-P. (1988) Les nématodes Syphaciine parasites de rongeurs et de lagomorphes. *Mém. Mus. Nat. Hist. Nat. Sér. A* **141**, 1-148.
- & QUENTIN, J.-C. (1985) Étude morphologique de six espèces nouvelles ou peu connues appartenant au genre *Syphacia* (Oxyuridae; Nematoda), parasites de Rongeurs Cricétidés et Muridés. *Bull. Mus. Nat. Hist. Nat. Sér. 4* **7**, 383-400.
- QUENTIN, J.-C. (1966) Oxyures de Muridae africains. *Ann. Parasit.* **41**, 443-452.
- (1971) Morphologie comparée des structures céphaliques et génitales des oxyures du genre *Syphacia*. *Ann. Parasit. Hum. Comp.* **46**, 15-60.
- RAVEN, H. C. (1935) Wallace's Line and the distribution of Indo-Australian mammals. *Bull. Am. Mus. Nat. Hist.* **68**, Article 4.
- SMALES, L. R. (1997) A review of the helminth parasites of Australian rodents. *Aust. J. Zool.* **45**, 505-521.
- (2001) *Syphacia longaecausta* n. sp. (Nematoda: Oxyuridae) Syphacinea from *Melomys* spp. (Muridae: Hydrominae) from Papua New Guinea and Irian Jaya, Indonesia. *Parasite* **8**, 39-43.
- STRAHAN, R. (1995) The Mammals of Australia (Reed Books, Chatswood).

**GASTRIC NEMATODES, INCLUDING A NEW SPECIES OF
ABBREVIATA (NEMATODA: PHYSALOPTERIDAE) FROM
THE MANGROVE MONITOR VARANUS INDICUS
(REPTILIA: VARANIDAE)**

By H. I. JONES

Summary

Jones, H. I. (000) Gastric nematodes, including a new species of *Abbreviata* (Nematoda: Physalopteridae) from the mangrove monitor *Varanus indicus* (Reptilia: Varanidae). Trans. R. Soc. S. Aust. 128(1), 53-59, 31 May, 2004.

Three species of nematode, *Tanqua tiara* (von Listow, 1879), *Heliconema longissima* (Ortlepp, 1922), and *Abbreviata melanesiensis* sp. nov., were recovered from the gastrointestinal tracts of 124 *Varanus indicus* (Daudin, 1802). *Tanqua tiara* occurred in two-thirds of the lizards, at a mean prevalence of 7.2 worms per infected host. It is suggested that the low intensity and geographically variable prevalence of this nematode may relate to the distribution of the invertebrate intermediate host in the discrete and discontinuous insular habit of the lizard. *Abbreviata melanesiensis* sp. nov. was recovered from two lizards, and is distinguished from other species in this genus principally by the enlarged tip of the right copulatory spicule, the thick sheath which envelops the retracted left spicule, the relatively conspicuous phasmids in females, and the elongated, thin-walled eggs. A single male *Heliconema longissima* was recorded.

Key Words: *Varanus indicus*, *Tanqua tiara*, *Abbreviata melanesiensis*, *Heliconema longissima*, Solomon Islands, Papua New Guinea, Indonesia, Australia.

**GASTRIC NEMATODES, INCLUDING A NEW SPECIES OF *ABBREVIATA*
(NEMATODA: PHYSALOPTERIDAE) FROM THE MANGROVE MONITOR
VARANUS INDICUS (REPTILIA: VARANIDAE)**

by H. I. JONES

Summary

JONES, H. I. (2000) Gastric nematodes, including a new species of *Abbreviata* (Nematoda: Physalopteridae) from the mangrove monitor *Varanus indicus* (Reptilia: Varanidae). *Trans. R. Soc. S. Aust.* 128(1), 53-59, 31 May, 2004.

Three species of nematode, *Tanqua tiara* (von Linstow, 1879), *Heliconema longissima* (Ortlepp, 1922), and *Abbreviata melanesiensis* sp.nov., were recovered from the gastrointestinal tracts of 124 *Varanus indicus* (Daudin, 1802). *Tanqua tiara* occurred in two-thirds of the lizards, at a mean prevalence of 7.2 worms per infected host. It is suggested that the low intensity and geographically variable prevalence of this nematode may relate to the distribution of the invertebrate intermediate host in the discrete and discontinuous insular habitat of the lizard. *Abbreviata melanesiensis* sp. nov. was recovered from two lizards, and is distinguished from other species in this genus principally by the enlarged tip of the right copulatory spicule, the thick sheath which envelops the retracted left spicule, the relatively conspicuous phasmids in females, and the elongated, thin-walled eggs. A single male *Heliconema longissima* was recorded.

KEY WORDS: *Varanus indicus*, *Tanqua tiara*, *Abbreviata melanesiensis*, *Heliconema longissima*, Solomon Islands, Papua New Guinea, Indonesia, Australia.

Introduction

The mangrove monitor, *Varanus indicus* (Daudin, 1802), has a wide and discontinuous distribution from Sulawesi in eastern Indonesia, east through Papua New Guinea and northern Australia to the Solomon, Caroline and Marshall Islands (De Lisle 1996). The taxonomy of the monitor lizards in the *Varanus indicus* complex has recently been revised (Boehme *et al.* 1994, Philipp *et al.* 1999) to include several closely-related species. *Varanus indicus* sensu lato is found close to water, on beaches or riverbanks, and in swampy and mangrove areas (Cogger 1992). It is largely a terrestrial feeder, and its diet principally comprises crabs (especially grapsoid), smaller reptiles, mammals and birds, and occasionally turtles' eggs (McCoy 1980). It is a diurnal lizard, and when alarmed will take to water (Cogger 1992), although in the Solomon Islands it will invariably climb a tree (McCoy 1980).

Confusion in the nomenclature of *Varanus* lizards has resulted in a number of nematodes being attributed erroneously to *Varanus indicus* from India (Ortlepp 1922, Mirza 1934, Sharief 1957, Deshmukh 1969, Ali & Ilyas 1969). Since these records are far to the west of the known geographical range of *V. indicus*, and as all state or imply that the lizards were locally obtained and were not exotic specimens held in captivity, it is probable that these nematode

records pertain to *V. bengalensis* (Daudin, 1802), or possibly *V. flavescens* (Hardwick and Gray, 1827) or *V. griseus koniecznyi* Mertens, 1954 (De Lisle 1996).

Little is known of the internal parasites of *Varanus indicus*. The nematode *Kalicephalus megacephalus* Schad, 1962 was described from this host from Florida Island in the Solomon Islands by Schad (1962). *Tanqua tiara* (Von Linstow, 1879) is primarily a nematode parasite of lizards in the genus *Varanus*, and has been recorded from a number of *Varanus* spp. from Africa to southeast Asia and northern Australia, in aquatic or coastal habitats, but has not hitherto been reported from *V. indicus* (see Gibbons and Keymer 1991). The present study was therefore undertaken to ascertain the nematode fauna of *Varanus indicus* sensu lato, as part of a study of the gastrointestinal nematodes of varanid lizards.

Materials and Methods

The results of dissections of 124 *Varanus indicus* are presented. Thirty seven *V. indicus* held in the collection of the Australian Museum, Sydney, and one from the collection of CSIRO Sustainable Ecosystems, Canberra, were examined. Dennis King forwarded nematodes recovered from stomach contents of 20 *V. indicus* collected from islands and small archipelagos of Bandaneira, Aru, Kai Besar, Yamdena and Selaru in the Moluccas in south and eastern Indonesia during Western Australian Museum/Museum Zoologicum Bogoriense expeditions in 1992/1993. In addition, nematodes from stomachs of sixty-six *V. indicus* collected at Maningrida in the Northern Territory by Tim Schultz

during 2001 were removed by Alain de Chambrier and identified by Ian Beveridge and the author. The snout-vent length (SVL) of 58 hosts examined varied from 135 and 550 mm (mean = 335mm). Measurements were not available from lizards from Maningrida. The viscera were removed, and stomachs (and the intestines from the Australian Museum specimens) examined for helminths. Food residues were noted. All nematodes collected were cleaned, and stored in 70% alcohol with 10% glycerine. They were subsequently cleared in chlorolactophenol for examination. All specimens have been returned to the Australian Museum, Western Australian Museum, CSIRO and the Australian Helminth Collection respectively.

Results

Helminths recovered. Three species of nematode were recovered. The predominant species was *Tanqua tiara*, which was present in 75/124 lizards (60.5%, Fig. 1); specimens lodged as Australian Museum W 28660-W 28674; CSIRO Canberra N5294; Western Australian Museum V 4374 and V 4375, and in the Australian Helminth Collection. Prevalence was highest in the lizards from Maningrida (84.8%), and lowest from the Moluccas and Solomon Islands (32.8%). Total mean intensity of

T. tiara was 7.2 worms/host. Four *V. indicus*, collected from Adelaide River and Maningrida in the Northern Territory, contained >20 *T. tiara* (22 – 123); in the remaining 71 infected hosts *T. tiara* numbers ranged from 1 – 16 (mean: 4.2). In four hosts some nematodes were attached with their heads buried in the stomach mucosa. A single male *Heliconema longissima* (Ortlepp, 1922) was recovered from a lizard from Maningrida in the Northern Territory. A new species of *Abbreviata* was recovered from two hosts collected from New Britain and from Woodlark Island, Papua New Guinea.

There was no relation between the size of the host lizard, type of food residues in the stomach, and the presence or intensity of infection with *T. tiara*. Both prevalence and intensity of this worm from lizards collected from the Moluccan islands in south-eastern Indonesia were lower (2 of 20 infected with one and two worms, respectively) than those collected from Papua New Guinea or the Solomon Islands, with highest prevalence and intensity in lizards from northern Australia. Neither of the two lizards with the new species of *Abbreviata* was concurrently infected with *T. tiara*. One of the two lizards infected with this species of *Abbreviata* was one of the largest dissected (500 mm SVL).

Food residues. In the 37 *V. indicus* from Papua New Guinea and the Solomon Islands, crustacea, in three

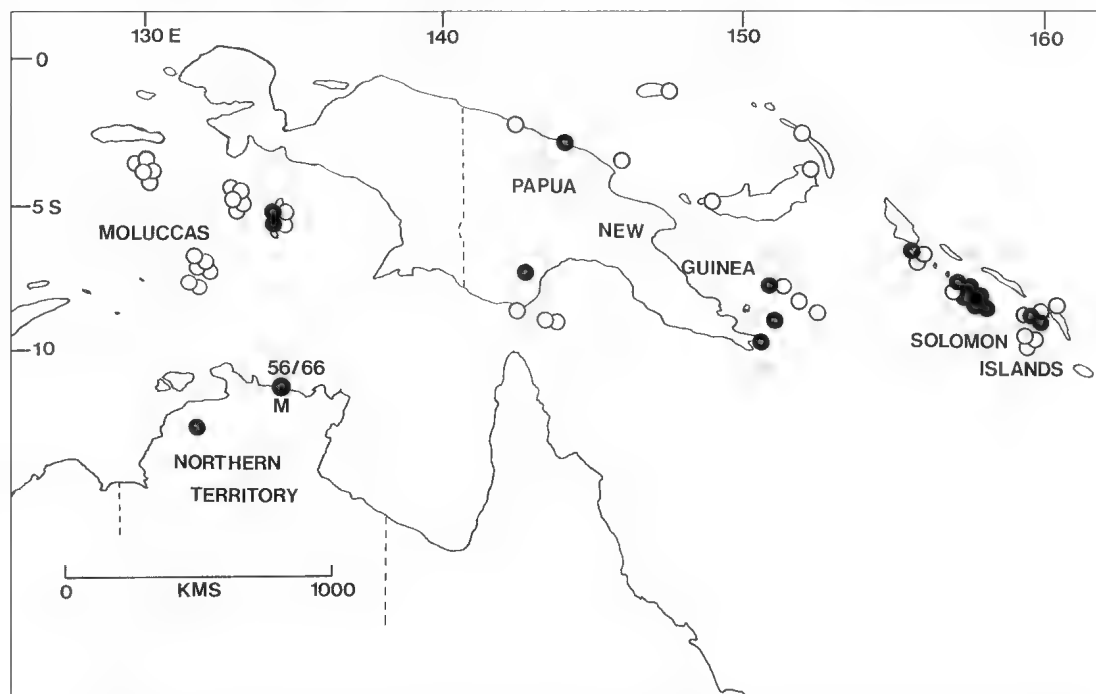


Fig. 1. Map showing distribution of *Tanqua tiara* in *Varanus indicus*. Open circle, lizard without infection; black circle, lizard with infection. M: Maningrida, where 56 of 66 lizards were infected. (No location data available for two lizards).

cases identifiable as crabs, formed the most commonly recovered food source, and occurred in 16 lizards. In addition, a snake (*Candoia* sp.; Boidae), an agamid lizard skull, an unidentified lizard, a frog, reptile eggs, cicadas, a grasshopper, and a beetle were each recovered from a single host stomach, and vertebrae from an unidentified animal, and molluscs from two hosts each. Stomach contents from the 20 lizards from the Indonesian islands included 10 with insect remains, one with a gecko, one with a bird, one with reptile eggs, one with a crab, and four with plant residues. Twenty one of these fifty seven stomachs had no food residues; no fish remains were identified.

Taxonomy

Order Spirurida
Superfamily Physalopteroidea
Family Physalopteridae

Genus *Abbreviata* Travassos, 1920.

Abbreviata melanesiensis sp. nov.

Holotype

Male, Australian Museum W 28675, from stomach of *Varanus indicus*, AM R129614, Amelei village, West New Britain, Papua New Guinea (06° 06' S, 150° 37' E), collected 27.xii.1988.

Allotype

Female, AM W 28676, same data as for holotype.

Paratypes

16 males, 9 females, 4 larvae/immatures, AM W 28677, same data as for Holotype. Additional non-type specimens: three males, four females and two immatures, AM W 28678, from *V. indicus* R124815, collected Guasopa, Woodlark Island, Milne Bay Province, Papua New Guinea (09° 15' S, 152° 56' E), collected 09.viii.1987.

Diagnosis

With characteristics of the genus, viz. two large lateral pseudolabia, with externolateral tooth present on each pseudolabium, a bifid internolateral tooth and two double pairs of submedian teeth; male with wide ornamented caudal alae united anteriorly on ventral surface of body, supported by four pairs of pedunculate papillae, markedly unequal spicules, females with vulva in anterior portion of body.

Mouth with dorsal and ventral corner denticles. Spicules well sclerotised, left four times length of right; left spicule in thick walled sheath, terminating in a very fine point, right spicule curved ventrally, with pointed, weakly-sclerotised enlargement at tip. Female tail slightly attenuated, vulva flush with body wall without extensions; eggs thin-shelled, elongate, length approximately twice width.

Description (Fig. 2)

Small to medium worms, males not greatly smaller than females, tapering at both ends, fine transverse cuticular striations. Mouth surrounded by two pseudolabia, each bearing large externolateral apical tooth and small bifid internolateral tooth. Bifid submedian tooth on dorsal and ventral border of each pseudolabium. Four to 5 small, regular denticles at dorsal and ventral median surface of each pseudolabium. Two sessile papillae and amphid on external surface of each pseudolabium. Cervical collar present. Nerve ring surrounds muscular oesophagus near its posterior end. Glandular oesophagus of uniform width, wider than muscular portion. Cervical papillae and excretory pore on external surface posterior to origin of glandular oesophagus.

Male

Caudal alae meet anteriorly, extend just beyond tip of tail posteriorly. Alae supported by four pairs of pedunculate pericloacal papillae and three pairs of very short pedunculate or sessile caudal papillae, of which the central pair is about one-third the distance between the first and second pair. Papillae on ventral surface sessile, 3 immediately anterior to the cloaca, and 2 pairs immediately posterior to the cloaca. Caudal tubercles arranged in rows, extending from anterior border of alae, converging towards cloaca, and running parallel to one another lateral to cloaca on ventral surface of tail and adjoining alae; diminishing in size posteriorly, terminating as small scattered tubercles at level of posteriormost caudal papillae. Spicules dissimilar, unequal. Left spicule approximately 4 times length of right, uniformly sclerotised, terminating in very fine tapering point, enclosed in conspicuous thick sheath. Right spicule thicker than left, heavily sclerotised, curved ventrally, and with a weakly-sclerotised pointed enlargement, slightly concave on one side, at the tip.

Female

Tail short, terminating in a slight attenuation; phasmids relatively conspicuous at two-thirds distance along tail. Vulva a transverse slit flush with body wall, without extensions or altered adjacent cuticle, posterior to commencement of intestine, about one-quarter of distance from anterior end of worm. Two ovaries, uterus with four branches, one of which often extends a variable distance anteriorly beside the posterior portion of glandular oesophagus. Eggs with smooth thin shells, elongate, embryos not visible, length almost twice width.

Measurements (mm; range with mean in brackets) Males (N:6): length 18–24 (21.7); maximum width 0.36–0.54 (0.45); muscular oesophagus length 0.26

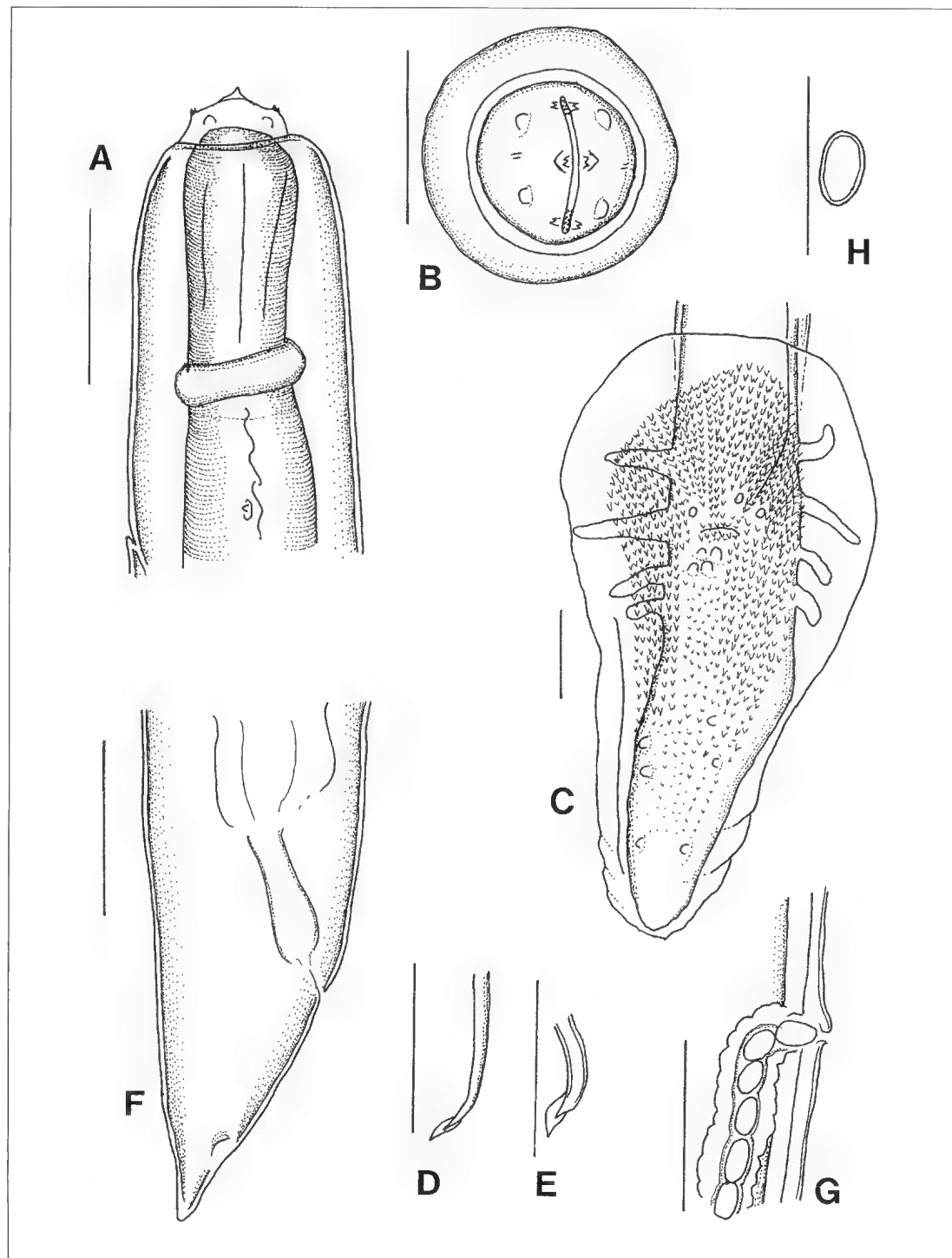


Fig. 2. *Abbreviata melanesiensis* sp. nov. A, anterior end, male paratype, lateral view; B, anterior end, *en face*, female paratype; C, male tail, slightly-oblique ventral view; D and E, distal tip of right spicule, male paratype; F, tail, female paratype, lateral view; G, eggs in oviduct and vulva, female paratype, lateral view; H, egg. Scale bars, E and H: 100µm, all other figures, 200µm.

– 0.36 (0.33); muscular oesophagus width 0.10 – 0.14 (0.12); glandular oesophagus length 2.8 – 3.3 (3.2); glandular oesophagus width 0.24 – 0.28 (0.26); nerve ring* 0.26 – 0.38 (0.32); cervical papillae* 0.36 – 0.68 (0.53); excretory pore* 0.56 – 0.72 (0.61); tail 0.96 – 1.32 (1.16); distance between caudal papillae 1 and 2, 0.056 – 0.16 (0.11); distance between caudal papillae 2 and 3, 0.14 – 0.19 (0.16); left spicule 1.320 – 1.680 (1.470); right spicule 0.280 – 0.360 (0.320). Females (N: 6) length 26 – 33 (29.3); maximum width 0.62 – 0.74 (0.70); muscular oesophagus length 0.36 – 0.44 (0.41); muscular oesophagus width 0.14 – 0.18 (0.15); glandular oesophagus length 3.36 – 4.40 (3.93); glandular oesophagus width 0.26 – 0.41 (0.32); nerve ring* 0.34 – 0.38 (0.36); cervical papillae* 0.48 – 0.60 (0.54); excretory pore* 0.62 – 0.86 (0.70); tail 0.34 – 0.44 (0.38); vulva† 1.9 – 3.7 (2.78); 19.4% – 27.8% (23.3%) of distance from anterior end (* distance from anterior end; † distance posterior to oesophago-intestinal junction).

Discussion

Taxonomy

Abbreviata melanesiensis sp. nov. is distinguished from other species of *Abbreviata* occurring in reptiles from the Australo-Papuan region by a suite of characters. The size, general form, characteristics of the anterior end and the male copulatory bursa are shared with a number of other species. However, the weakly-sclerotised enlargement at the tip of the right spicule is unique; a similar feature occurs in *A. hastaspicula* Jones, 1979, in which species however it is well sclerotised (Jones 1979). Furthermore, in that species the left spicule is considerably shorter (0.620 – 0.700 mm) and the right spicule longer (0.590 – 0.670 mm; Jones 1979) than in *A. melanesiensis* sp. nov., and the sclerotisation of the left spicule often appears discrete and discontinuous: in addition, in *A. hastaspicula* the female bears a tubular extension from the vulva. Eggs of *A. melanesiensis* sp. nov. are elongate and thin walled; most species of *Abbreviata* in this region possess eggs with thicker and denser shells (Jones 1983b, 1988) except *A. hastaspicula* and *A. perenticola* Jones, 1985, whose thin shelled eggs are subspherical. Other characteristics which differentiate this species include less disparity in length between males and females, the thick sheath that envelops the retracted left spicule, and the readily visible phasmids on tails of females. In other species of *Abbreviata* described from Australia and Papua New Guinea, except *A. levicauda* Jones, 1983, from *V. tristis* (Schlegel, 1839) the penultimate caudal papillae are closer to the anterior papillae (Jones 1986) than in *A. melanesiensis* sp. nov. The

enlargement at the tip of the right spicule distinguishes *A. melanesiensis* sp. nov. from six other species of *Abbreviata* recorded from Papua New Guinea, viz. *A. oligopapillata* (Kreis, 1940) (see Jones 1979), *A. multipapillata* (Kreis, 1940), *A. natricis* (Kreis, 1940), *A. heterocephala* (= *Kreisiella*) (Kreis, 1940), *A. confusa* Johnston & Mawson, 1942, (see Jones 1983a) and *A. kaulensis* (Jones, 1979). *A. borneensis* Schad, 1959 from *V. rudicollis* Gray, 1843 in Sarawak also has the posterior portion of the tail free from tubercles, as in *A. oligopapillata* (Schad 1959). In *A. melanesiensis* sp. nov. the delicate enlargement at the tip of the right spicule is not visible unless this is extended through the cloaca, and if this spicule is retracted, dissection is necessary to ascertain its character; all specimens in the type host had the right spicules retracted, but in all four males in the second host the right spicules were extended and this character was clearly visible. The small denticles at the dorsal and ventral mouth margins are often not visible if obscured by the cervical collar.

Biology

The absence of a relationship between host size and numbers of *T. tiara* contrasts with the findings of Shine *et al.* (1998), who found that *T. tiara* were present at a higher intensity in juvenile *V. salvator*. They also found a significant difference in infection with this worm between two sites in Sumatra, though the intensity of worms was similar to findings from *V. indicus* in the present study (mean 6.1 worms per host). The arthropod intermediate host for *T. tiara* is not known, but as *Varanus* specimens infected with this worm inhabit swampy, mangrove or riverine habitats, a crustacean intermediate host is possible. Although *V. indicus* feed on a wide range of prey, the fact that crustacean remains were found in 16 of 37 from Papua New Guinea and the Solomon Islands, and in only 2 of 20 from the Moluccas, (food data not available from lizards from Maningrida) illustrate local or regional differences in prey availability. The distribution of the worm in the present study may be related to the discontinuous nature of insular habitats. In the present study highest intensity of *T. tiara*, 22 – 123 worms, occurred in *V. indicus* examined from northern mainland Australia (Adelaide River and Maningrida), which may provide both more opportunities for the spread of worms and intermediate hosts than from small isolated habitats. Furthermore, *T. tiara* have been reported from *V. panoptes* Storr, 1980, *V. gouldii* (Gray, 1838) and *V. mertensi* Glauert, 1951, from aquatic habitats in northern Australia at mean intensities of 18.9 (max. 120 worms), 20.5 (max. 50 worms) and 7.2 (max. 30 worms) respectively; an absence of correlation with *Abbreviata* spp. infection

was also noted in that study (Jones 1988). The similar species *T. ophidis* Johnston & Mawson, 1948, described from the aquatic file snake *Acrochordus* sp. was present in all eight *Acrochordus* sp. examined from north and northwest coastal Queensland, at numbers ranging from seven to 179 per host (mean, 51); (Jones 1978). As *V. indicus*, *Acrochordus arafurae* McDowell, 1979 and *A. granulatus* (Schneider, 1799) are sympatric over much of their range, it is possible that these two species of *Tanqua* are also sympatric.

The single male *H. longissima* reported in the present study was probably an accidental infection, taken with infected prey. The type host and type locality of *Heliconema longissima* (Ortlepp, 1922) are given as 'snakes, Australia', although all other specimens have been recorded from anguilliform fish, and Ogden (1969), considered that the type host identification is probably in error. However, *H. longissima* occurred in 3/5 specimens of the aquatic colubrid snake *Fordonia leucobalia* (1, 23 and 41 nematodes per host; Jones 1978).

The scarcity of *Abbreviata melanesiensis* sp. nov. in *V. indicus* contrasts with findings of prevalence and intensity of *Abbreviata* spp. in other species of *Varanus* and other large terrestrial reptiles in northern and arid Australia, in several species of which infection with *Abbreviata* spp. occurs at high prevalence and intensity (Jones 1983b, 1988). Epidemiological evidence suggests that termites might have a role to play in the life-cycles of species of *Abbreviata* from arid regions (Jones 1995). Since only two *V. indicus* were infected with *Abbreviata* sp., no conclusions can be drawn from the absence of concurrent infection with *T. tiara*. Since *Varanus indicus* feeds on a wide variety of invertebrate (and, in the larger specimens, vertebrate prey; McCoy 1980) the nematodes present may relate to differences in diet; the predominance of aquatic prey in these lizards suggests that the intermediate hosts of *T. tiara* may be aquatic invertebrates. The fact that one of the two hosts infected with *A. melanesiensis* was particularly large may be significant. The larger of the two infected lizards contained a *Candoia* sp. snake prey item, and though it is possible that this

Abbreviata infection was spurious, this is unlikely as several of the nematodes were already attached to and apparently feeding on the external surface of the snake.

Conclusion

This study demonstrates that despite the wide range of prey items consumed by *V. indicus*, this lizard supports gastric nematodes in low numbers, and at a moderate prevalence, with only three species recorded. No intestinal nematodes were recovered. It is possible that the large range of prey types may inhibit the development of parasite cycles, particularly in parasite species with narrow intermediate-host specificity. The low intensity of *T. tiara* and geographically uneven distribution may relate to the insular and discontinuous nature of the region from which *V. indicus* was examined; in this regard the higher intensities of this nematode recorded from other species of *Varanus* in northern mainland Australia may be significant. Further conclusions cannot be drawn without knowledge of the arthropod intermediate hosts required by this nematode to complete its life-cycle. Studies on the gastrointestinal parasites of other larger reptiles in this region may reveal a wider range of hosts for *A. melanesiensis*.

Acknowledgements

I thank Allen Greer for allowing me access to the lizards under his care in the Australian Museum, and for providing facilities, Ross Sadler for practical assistance, David Spratt for allowing me to examine a lizard in the collection of CSIRO Sustainable Ecosystems, Canberra, and Brad Maryan for assistance at the Western Australian Museum. I am grateful to Alain de Chambrier for collecting nematodes from lizards collected at Maningrida; to Ian Beveridge for identifying and forwarding these specimens, and to the late Dennis King for collecting nematodes during the course of his own studies, and to Mrs. Ruth King for making his papers available for my perusal.

References

- ALI, S. M. & ILYAS, R. (1969) *Neoxysomatium longicaudatum* n. sp. from *Varanus indicus* in Marathwada, India. *Marathwada Univ. J. Science* **8**, 73-75.
- BOLHME, W., HORN, H. G. & ZIEGLER, T. (1994) On the taxonomy of the Pacific monitor lizards (*Varanus indicus* complex): resurrection of *Varanus doreanus* (A. B. Meyer, 1874) and description of a new species. *Salamandra* **30**, 119-142.
- COGGER, H. G. (1992) Reptiles and Amphibians of Australia. (5th Edition, Reed, Chatswood, NSW 2067; 1-775).
- DE LISLE, H. F. (1996) The Natural History of Monitor Lizards. Krieger Publishing Company, Malabar, Florida, 1-201.
- DESHMUKH, P. G. (1969) A new species of the genus *Herpetostromylus* (Nematoda) from *Varanus indicus*. *Vest. Cesk. Spol. Zool.* **33**, 211-213.

- GIBBONS, L. M. & KEYMER, I. F. (1991) Redescription of *Tanqua tiara* (Nematoda, Gnathostomatidae), and associated lesions in the stomach of the Nile monitor lizard (*Varanus niloticus*). *Zool. Scr.* **20**, 7-14.
- JONES, H. I. (1978) Gastrointestinal nematodes from aquatic Australian snakes. *Mem. Queensl. Mus.* **18**, 243-254.
- _____ (1979) Nematodes from Papua New Guinean snakes. *Mem. Queensl. Mus.* **19**, 393-397.
- _____ (1983a) A collection of nematodes from snakes from Papua New Guinea. *Syst. Parasitol.* **5**, 131-134.
- _____ (1983b) *Abbreviata* (Nematoda: Physalopteroidea) in lizards of the *Varanus gouldii* Complex (Varanidae) in Western Australia. *Aust. J. Zool.* **31**, 285-298.
- _____ (1986) Differences in caudal morphology in male *Abbreviata levicauda* (Nematoda: Physalopteridae) in two sympatric species of *Varanus* (Reptilia: Varanidae). *J. Parasitol.* **72**, 185-186.
- _____ (1988) Nematodes from nine species of *Varanus* (Reptilia) from tropical northern Australia, with particular reference to the genus *Abbreviata* (Physalopteridae). *Aust. J. Zool.* **36**, 691-708.
- _____ (1995) Gastric nematode communities in lizards from the Great Victoria Desert, and an hypothesis for their evolution. *Aust. J. Zool.* **43**, 141-164.
- McCOY, M. (1980) Reptiles of the Solomon Islands. Wau Ecology Institute. Handbook **7**. Wau Ecology Institute, Wau, Papua New Guinea.
- MIRZA, M. B. (1934) *Sciurus palmarum* als ein interessante Wirt von *Physaloptera* sp. *Z. f. ParasitKde* **6**, 638-641.
- OGDEN, C. G. (1969) A revision of the genus *Heliconema* Travassos, 1919, Physalopteridae (Nematoda). *J. Nat. Hist.* **3**, 423-431.
- ORTLEPP, R. J. (1922) The nematode genus *Physaloptera* Rud. *Proc. Zool. Soc. Lond.* 999-1107.
- PHILIPP, K. M., BOEHME, W. & ZEIGLER, T. (1999) The identity of *Varanus indicus*; redefinition of a sibling species coexisting at the type locality (Sauria, Varanidae, *Varanus indicus* group). *Spixiana* **22**, 273-287.
- SCHAD, G. A. (1962) Studies on the genus *Kalicephalus* (Nematoda: Diaphanocephalidae). II. A taxonomic revision of the genus *Kalicephalus* Molin 1861. *Canad. J. Zool.* **40**, 1035-1065.
- SHARIEF, A. (1957) On a new species of trichostrongylid nematode from Hyderabad, India. *Ann. Mag. Nat. Hist. ser.12*, **10**, 705-709.
- SHINE, R., AMBARIYANTO, HARLOW, S. & MUNPUNI (1998) Ecological traits of commercially harvested water monitors, *Varanus salvator*, in northern Sumatra. *Wildlife Res.* **25**, 437-447.

ENRICHMENT-PLANTING OF THE WOODY CLIMBERS MARSDENIA AUSTRALIS AND RHYNCHARRHENA LINEARIS IN NORTH-WESTERN VICTORIA

*By R. F. PARSONS**

Summary

Parsons, R. F. (2000). Enrichment-planting of the woody climbers *Marsdenia australis* and *Rhyncharrhena linearis* in north-western Victoria. Trans. R. Soc. S. Aust. 128(1), 61-66, 31 May, 2004.

Marsdenia australis and *Rhyncharrhena linearis* are woody climbers (family Asclepiadaceae) found in semi-arid to arid areas of all mainland states of Australia. Where studied, they are declining drastically, probably due to grazing. In Victoria, their conservation status is vulnerable. In 1991, in Hattah-Kulkyne National Park, a site was found carrying single plants of each species. At this site, 384 seedlings and 1,741 seeds of *Marsdenia* and 240 seedlings of *Rhyncharrhena* were planted underneath trees of *Eucalyptus socialis* in 1991-1992, half of the seedlings in mammal-proof cages. After high seedling mortality due to mammal grazing and especially to drought in the first summer, only six of the planted seedlings, all of *Marsdenia*, survived by the end of 1992. All of these, and a further 15 *Marsdenia* plants derived from seed sowing, have survived until present. Most of them have climbed up nets and ropes provided onto the stems of three *Eucalyptus* host plants and at least two of them have produced fruits. *Marsdenia* is likely to be an obligate outbreeder, in which case the genotypes introduced to the site will be vital in allowing future seed production there. Implications of the work for conservation and management are stated.

Key Words: Drought, enrichment planting, kangaroo grazing, mallee vegetation, *Marsdenia australis*, *Rhyncharrhena linearis*, seedling mortality, woody climbers.

ENRICHMENT-PLANTING OF THE WOODY CLIMBERS *MARSDENIA AUSTRALIS* AND *RHYNCHARRHENA LINEARIS* IN NORTH-WESTERN VICTORIA

by R. F. PARSONS*

Summary

PARSONS, R. F. (2000). Enrichment-planting of the woody climbers *Marsdenia australis* and *Rhyncharrhena linearis* in north-western Victoria. *Trans. R. Soc. S. Aust.* 128(1), 61-66, 31 May, 2004.

Marsdenia australis and *Rhyncharrhena linearis* are woody climbers (family Asclepiadaceae) found in semi-arid to arid areas of all mainland states of Australia. Where studied, they are declining drastically, probably due to grazing. In Victoria, their conservation status is vulnerable. In 1991, in Hattah-Kulkyne National Park, a site was found carrying single plants of each species. At this site, 384 seedlings and 1,741 seeds of *Marsdenia* and 240 seedlings of *Rhyncharrhena* were planted underneath trees of *Eucalyptus socialis* in 1991-1992, half of the seedlings in mammal-proof cages. After high seedling mortality due to mammal grazing and especially to drought in the first summer, only six of the planted seedlings, all of *Marsdenia*, survived by the end of 1992. All of these, and a further 15 *Marsdenia* plants derived from seed sowing, have survived until present. Most of them have climbed up nets and ropes provided onto the stems of three *Eucalyptus* host plants and at least two of them have produced fruits. *Marsdenia* is likely to be an obligate outbreeder, in which case the genotypes introduced to the site will be vital in allowing future seed production there. Implications of the work for conservation and management are stated.

KEY WORDS: Drought, enrichment-planting, kangaroo grazing, mallee vegetation, *Marsdenia australis*, *Rhyncharrhena linearis*, seedling mortality, woody climbers.

Introduction

Two species of lianes (woody climbers) in the family Asclepiadaceae, *Marsdenia australis* and *Rhyncharrhena linearis*, occur in semi-arid and arid areas of all mainland states of Australia. In Victoria, both species are declining drastically, probably due to grazing. While small sucker shoots can be found when grazing pressure is low, no seedlings at all can be found, even in the absence of vertebrate grazing (Nichols, Browne & Parsons, 1991). The primary aim of the work was to investigate seed and seedling survival in the field to assist the conservation management of the species, both of which have a conservation status currently rated as vulnerable Victoria-wide (Victoria: Department of Natural Resources & Environment, unpublished). However, we hoped that any plants surviving from the experiments would be left to augment naturally-occurring populations. The work began as a B.Sc. (Honours) project from February to September 1991 (Smith, 1991).

Methods

Hattah-Kulkyne National Park was chosen for the work, being an extensive biological reserve carrying both species. At present, only 12 naturally-occurring *Marsdenia* plants are known there (Fiona Murdoch,

pers. comm., 20 December 2002). The work was carried out near one of these, which has a *Rhyncharrhena* plant nearby.

The study site in Hattah-Kulkyne National Park is within the Mournpall Block, 0.6 km along Jasmine Track from its N end, then 0.2 km WSW of the Track (Fig. 1). The fenced *Rhyncharrhena* plot no. 9E is about 50 m away.

The area is *Eucalyptus socialis* tall shrubland ('mallee scrub') on sandy loam topsoils. After various episodes of heavy grazing by stock and rabbits since 1847, stock grazing was stopped in 1974 (Parks Victoria records). Subsequent rabbit control meant that rabbit numbers were 'very low' during the first year of the project (D. Major personal communication). There was also grazing by a population of western grey kangaroos, estimated at 800 in the 5,700 ha Mournpall Block during 1991 (D. Major personal communication).

All seed used was collected between 1988 and 1991 from the Red Cliffs area (50 km from the plots), *Marsdenia* from sites 1 and 3 and *Rhyncharrhena* from site 1 of Nichols, Browne & Parsons (1991). Germinability of seed lots was established in a growth cabinet using a 10 hour photoperiod at 25/15° C after plume removal. Seedlings to transplant into the field were produced by planting germinated seed into sandy loam, vermiculite and perlite (2:1:1) in pots in the same growth cabinet. At four weeks of age they were placed outside to harden and then planted at the field site.

* Botany Department, La Trobe University, Bundoora, VIC 3086, Australia.

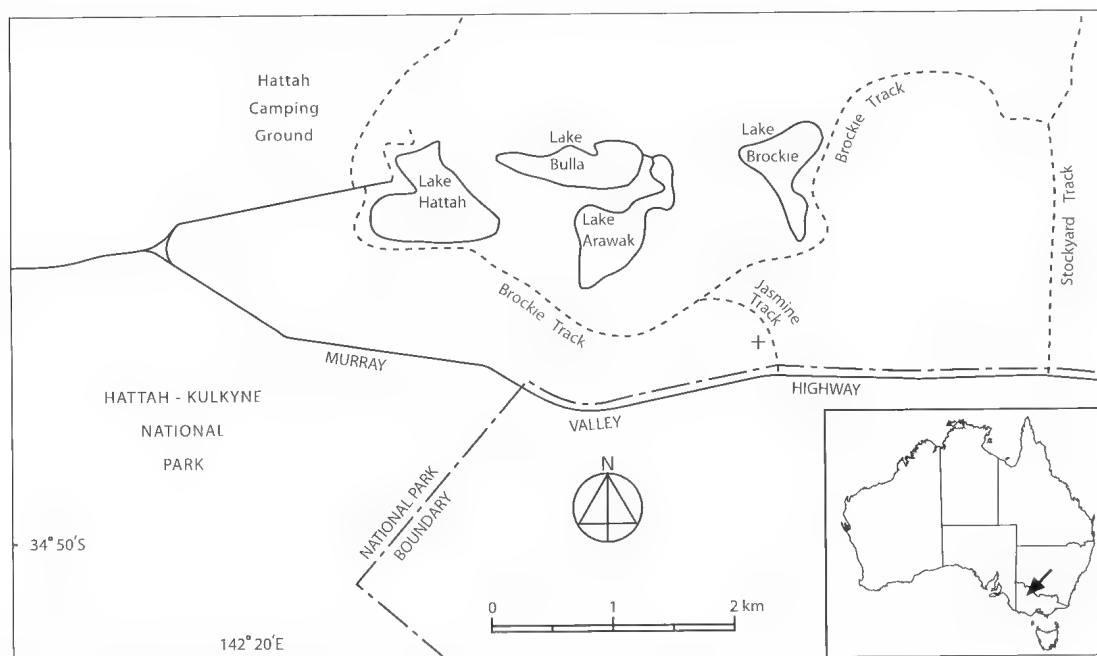


Fig. 1. Location of study area in north-western Victoria. Study site shown as cross west of Jasmine Track.

For both species, as fruiting seems only to occur in plants climbing in shrubs or trees (Nichols, Browne & Parsons, 1991), all seedlings were planted beneath low branches of mature *Eucalyptus socialis* trees. Four trees growing in an area of 50 m radius were used (Fig. 2) with four sites selected beneath each tree crown. For *Marsdenia* seedlings, at each of four planting dates from March to July 1991, one site under each tree was chosen at random and planted, providing four replicates. Each site consisted of a caged and an uncaged plot (for seedlings) side-by-side. Cages were 40 x 40 x 30 cm. Thus for *Marsdenia* the design was 4 trees x 4 planting times x 2 treatments (caged/uncaged) x 12 seedlings – a total of 384 seedlings planted. The *Rhyncharrhena* plantings were similar, but only 240 seedlings were available.

Before planting, litter and understorey plants were removed and plots made level by rake. Seedlings were planted 10 cm apart, the species intermingled. The wire mesh cages were flanged at the base to deter rabbit entry via burrowing.

The plots were watered to try to minimize seedling deaths from water deficiency. At each planting date, enough water to saturate the surface 5 cm of soil was added, both to the plots to be planted and to all plots planted previously. Water poured onto the sites was stopped from running off by infiltrometer rings put in place until infiltration was complete.

At all planting and inspection dates, all herbs other

than *Marsdenia* and *Rhyncharrhena* were identified, counted and removed from the plots by manual uprooting. The plots were monitored in September 1991, four times in 1992–4 and finally in May 2002 (Table 2).

Eleven *Marsdenia* fruits containing a total of 1741 filled seeds were left over from the 1991 experiment. We removed their plumes and sowed them under a shallow soil covering in three of the cages on 2 March 1992 (rather than discard them). At the same time, surviving seedlings were marked with stakes to distinguish them from plants of seed origin. On 5 May 1994, nets or ropes made of natural fibres were positioned to provide all surviving plants with a pathway so that they could twine upwards into *Eucalyptus* crowns. This necessitated cutting the tops out of the cages.

Results

Survival of planted seedlings inside cages, after a winter of mild temperatures (coldest single night of 1° C) and before the severe water deficit of summer, was high (84–85%) for both species (Table 1). Judging from plant symptoms and climatic data, by far the main cause of mortality in the cages up until September 1991 was soil water deficit.

Analysis of bite marks suggested that the much lower survival outside cages (49–52%) was due to either rabbit or kangaroo grazing.

TABLE 1. Number of survivors on 3 September 1991 of seedlings planted from March to July 1991.

	Number planted	Number surviving	Percentage survival
<i>Marsdenia</i>			
Caged	192	164	85
Uncaged	192	100	52
<i>Rhyncharrhena</i>			
Caged	96	81	84
Uncaged	144	71	49

TABLE 2. Height, leaf number and survival at five dates of 384 seedlings of *Marsdenia australis* planted from March to July, 1991. na – not available.

Date	Sep 91	Mar 92	Dec 92	Dec 93	May 94	May 02
Age (yr) (approx.)	<1	1	1.5	2.5	3	11
Number of survivors	264	9	6	6	6	6
Mean height (cm)	na	2	5	19	na	163
Mean leaf number	na	6	8	21	na	na

TABLE 3. Height, leaf number and survival at four dates of plants which germinated from 1741 seeds of *Marsdenia* sown on 2 March 1992. na – not available.

Date	Dec 92	Dec 93	May 94	May 02
Age	9 mo	1 yr 9 mo	2 yr 3 mo	10 yr 3 mo
Number of plants alive	22	67	77	15
Maximum height (cm)	3	7	na	270
Maximum leaf number	6	14	na	na

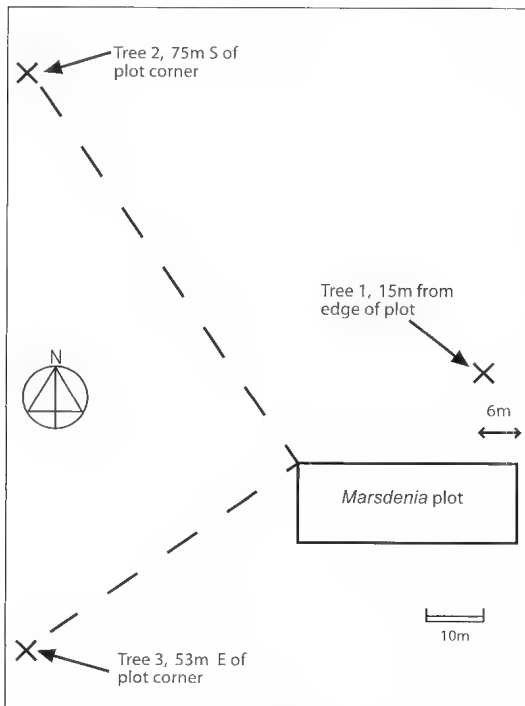
The alien annual weed *Brassica tournefortii* (Mediterranean Turnip) was always by far the most common species appearing in the plots as seedlings (cover from 45 to 80%) followed in order by the natives *Sclerochlamys brachyptera* (Short-wing Saltbush) and *Zygophyllum* spp. (Twinleaf) and the alien *Salvia verbenaca* (Wild Sage).

After water deficits in summer, by March 1992 all 152 *Rhyncharrhena* seedlings and all except nine of the 264 *Marsdenia* seedlings had died (Table 2), presumably mostly from drought and to a lesser extent from grazing (all but one of the nine were inside cages). Number of survivors fell to six caged plants by December 1992 but all six were still alive more than 11 years later (Table 2).

The seeds sown in March 1992 germinated at various times between then and May 1994, when 77 plants were seen. Fifteen of these were still present ten years later (Table 3). One tree crown had no surviving *Marsdenia* seedlings and is not shown in Fig. 2.

In the absence of other support, it is common for *Marsdenia* stems to twine around themselves to form tightly plaited ropes which can be up to 6 m long and 35 mm in diameter (see Fig. 7 in Nichols *et al.*, 1991). This occurred beneath all three host trees which had surviving *Marsdenias* under them in the present study, each plait involving from two to seven individual plant stems (Table 4). In fact all plants which reached from the soil surface to a host tree were members of such plaits or systems of stems.

Marsdenia is an apical stem twiner, a behaviour said to be effective in climbing tree trunks of up to 100 mm diameter at breast height but seldom bigger ones (Hegarty and Clifford, 1984). In the present study, by May 2002, only one *Marsdenia* stem had completely encircled the stem of a host tree: a stem of 50 mm diameter belonging to host tree 3, where the second system of *Marsdenia* stems is also firmly attached (at a host stem fork; Table 4). However, the only other two systems of stems to have reached a stem of their host tree (at host trees 1 and 2; Figures 3 and 4; Table 4) were less securely attached, with a

Fig. 2. Location of the three trees where *Marsdenia* has been established near Jasmine Track.

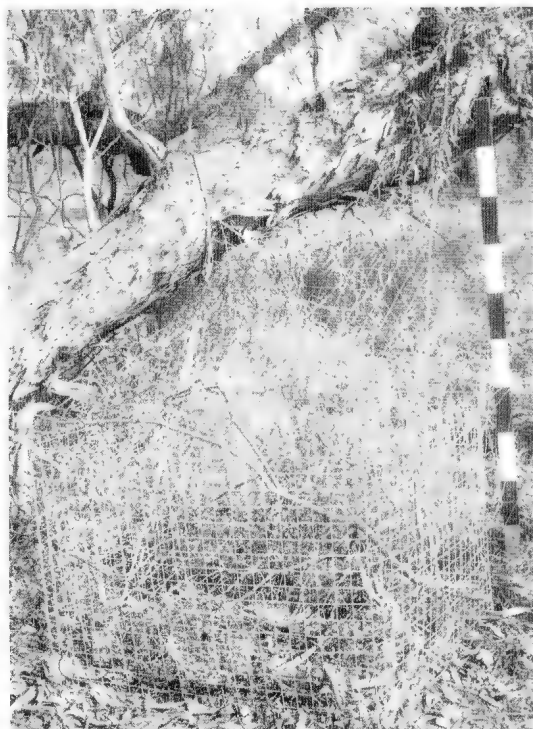


Fig. 3. Cage with top cut out at host tree 1. *Marsdenia* has climbed the net provided to reach stem of host (*Marsdenia* not clearly visible). Scale graduated in 10 cm intervals. 14 May 2002.



Fig. 4. Cage with top cut out at host tree 2. *Marsdenia* has climbed the rope provided to reach stem of host. Scale as in Fig. 3. 14 May 2002.

TABLE 4. Height, stem diameter and notes on attachment and reproduction of *Marsdenia* plants on 14 May 2002, including plants derived from planting both seeds and seedlings.

Location	No. of plants	Maximum height (m)	Maximum stem diameter (mm)	Attachment to host	Reproduction
a) Original (non-planted) plant in fenced plot	1	6	8	Fully attached; climbing into crown.	28 suckers <20 cm high up to 8 m from parent plant.
b) Host tree 1	4	1.2	2	Three plants twined together up net and attached to bark of big host stem.	Two suckers climbing in dead annual plants in cage
c) Host tree 2	2	1.8	3	The 2 plants twined together up rope; supported by upper knot in rope. Two shoot tips inside bark of host.	None
d) Host tree 3					
(i) from seedlings	3	1.6	4	The 3 plants twined together up net. Now firmly attached to stem fork of host.	One young, attached fruit
(ii) from seeds	12	2.7	4	Seven plants twined together up net. Firmly twined around host stem.	Four attached, mature fruits. Three suckers

few shoot tips held between attached dead bark and the main stem of the host (Table 4). Because of this, and because the host stems may be too large for easy *Marsdenia* encirclement (tree 1 stem diameter 230 mm; tree 2, 170mm), the *Marsdenia* stem systems have since been tied to these host trees (Fiona Murdoch, pers. comm., 5 December 2002).

While stem diameters of long-established *Marsdenia* plants reach 8 to 10 mm (Nicholls *et al.*, 1991; Table 4), the 11-year-old plants have only reached a maximum of 4 mm (Table 4). Some young plants have already produced shoot suckers from the roots as is normal in adult plants of *Marsdenia* (Table 4). In the absence of support, such shoots remain small and fail to produce fruit (Nichols *et al.*, 1991). Two plants carried fruit in May 2002 (Table 4) although it is not known if they represent the first fruit crop.

Discussion

In an area which carried a single naturally-occurring *Marsdenia* plant, the present work has established an additional 21 individuals on three host trees. The conditions provided included complete protection from vertebrate grazing for three years and supplementary watering and removal of competing seedlings in autumn-winter of year one. The huge mortality late in year one was not surprising given that, in this climate, summer drought is the main cause of death for perennial seedlings in their first year (see e.g. Parsons, 1994). For efficiency, future enrichment-plantings in this climate should allow for summer watering in case of drought, despite the possible favouring of unsuitable genotypes.

Hobbs and Atkins (1991) also recorded the presence of dense, non-native annuals including *Brassica tournefortii*. Future workers in mallee vegetation should note that such annuals are capable of severely inhibiting regeneration by native perennials (Hobbs and Atkins 1991). In the present study, it is not clear to what extent clearing the plots influenced density of alien annuals.

In *Marsdenia* as in other asclepiad vines, root suckering allows clones to establish and it is possible that such clones may be capable of persisting more or less indefinitely (e.g. see Penalosa, 1984).

However, it is common for species in family Asclepiadaceae to be obligate outbreeders. In such species, clone formation can cause extensive self-pollination and hence cause fruit set to be low or absent (see references in Nichols *et al.*, 1991). In the present case, the genotypes we introduced from outside the area may be vital in allowing outbreeding and hence seed production.

The greater success of *Marsdenia* planting than *Rhyncharrhena* may be because the tuberous root of *Marsdenia* gives it greater drought avoidance than the latter (see Nichols *et al.*, 1991).

Work is now needed to check the conservation status of *Marsdenia* and *Rhyncharrhena* in other areas of inland Australia. Although *Marsdenia* was recorded from as many as 19 out of 1,143 sites in the Stony Deserts of South Australia (Brandie 1998), we need to know to what extent grazing and other factors are allowing current recruitment both here and elsewhere. In Victoria, the populations of both species recorded at Pink Lakes State Park and three other reserves by Nichols *et al.* (1991) should be relocated and monitored. In particular, it should be noted that the present study and Nichols *et al.* (1991) only saw fruiting of both *Marsdenia* and *Rhyncharrhena* when they were climbing in shrubs or trees. The only *Rhyncharrhena* plants seen at Pink Lakes were 22 suckers in an area lacking any potential host plants. Because installing tree guards 300 mm high produced increased *Rhyncharrhena* shoot growth without fruit production (Nicholls *et al.*, 1991), host plants should now be established there. Other work on vine enrichment-planting, on the depleted vine *Pararistolochia praevenosa*, also shows that a supporting host plant is a requirement for fruiting (Sands *et al.* 1997; Sands, pers. comm.).

As for many other native plant species, the palatability of *Marsdenia* and *Rhyncharrhena* needs to be considered in managing mammal numbers at Hattah-Kulkyne National Park and other areas.

Acknowledgements

I thank J.H. Browne for providing seed, P. and F. Murdoch, T. Phillips and M. Bartley for help and Parks Victoria for financial support. The work was carried out under permit numbers 901/701, 912/076 and 10001922.

References

- BRANDLE, R. (1998) "A Biological Survey of the Stony Deserts of South Australia 1994-1997" (Department for Environment, Adelaide).
- HEGARTY, E. E. and CLIFFORD, H. T. (1984) Climbing angiosperms in the Australian flora. pp. 105-120 *In* Werren, G. & Kershaw, A.P. (Eds) "*The Rainforest Legacy. Australian National Rainforests Study. Vol. 2*" (Monash University, Melbourne).
- HOBBS, R. J. & ATKINS, L. (1991) Interactions between annuals and woody perennials in a Western Australian nature reserve. *J. Veg. Sci.* **2**, 643-654.
- NICHOLS, K. M., BROWNE, J. H. and PARSONS, R. F. (1991) Ecology of two asclepiad lianes in semi-arid Victoria. *Proc. R. Soc. Vict.* **103**, 93-112.
- PARSONS, R. F. (1994) Eucalyptus scrubs and shrublands. pp. 291-319 *In* Groves, R.H. (Ed) "*Australian Vegetation*" 2nd ed. (Cambridge University Press, Cambridge).
- PENALOSA, J. (1984) Basal branching and vegetative spread in two tropical rainforest lianes. *Biotropica* **16**, 1-9.
- SANDS, D. P. A., SCOTT, S. E. & MOFFATT, R. (1997) The threatened Richmond birdwing butterfly (*Ornithoptera richmondia*[Gray]): a community conservation project. *Mem. Mus. Vict.* **56**, 449-453.
- SMITH, B. C. (1991) Ecological studies of seasonal and biotic effects on seedling recruitment of two asclepiad lianes. B.Sc. (Honours) thesis, Botany Department, La Trobe University.

**BREINLIA (BREINLIA) VENTRICOLA SP. NOV., A NEMATODE
PARASITE FROM THE HEART OF THE RED KANGAROO,
MACROPUS RUFUS, IN WESTERN AUSTRALIA**

By D. M. SPRATT & R. P. HOBBS†*

Summary

Spratt, D. M. & Hobbs, R. P. (2004) *Breinlia (Breinlia) ventricola* sp. nov. (Nematoda: Filarioidea) from the heart of the red kangaroo, *Macropus rufus*, in Western Australia. *Trans. R. Soc. S. Aust.* 128(1), 67-71, 31 May, 2004.

Breinlia (Breinlia) ventricola sp. nov., is described from the right ventricles and pulmonary arteries of the red kangaroo, *Macropus rufus* (Desmarest, 1822), from the Pilbara region of Western Australia. It is the largest and most robust species of *Breinlia (Breinlia)* known to date and is distinguished from all other species by the close similarity in size between males and females, the presence of filamentous membrane surrounding the distal tip of the left spicule and the presence of a pair of caudal glands secreting a material which adheres to the caudal end of some fixed specimens, masking external cuticular features. The new species is most similar to *B. (B.) trichosuri*, *B. (B.) boltoni* and *B. (B.) mundayi* but distinguished from all 3 by its much greater size and the absence of internolateral cephalic papillae.

Key Words: Nematoda, marsupials, kangaroo, *Breinlia*, new species, *Macropus*.

**BREINLIA (BREINLIA) VENTRICOLA SP. NOV., A NEMATODE PARASITE
FROM THE HEART OF THE RED KANGAROO, *MACROPUS RUFUS*,
IN WESTERN AUSTRALIA.**

by D. M. SPRATT* & R. P. HOBBS[†]

Summary

SPRATT, D. M. & HOBBS, R. P. (2004) *Breinlia (Breinlia) ventricola* sp. nov. (Nematoda: Filarioidea) from the heart of the red kangaroo, *Macropus rufus*, in Western Australia. *Trans. R. Soc. S. Aust.* **128**(1), 67-71, 31 May, 2004.

Breinlia (Breinlia) ventricola sp. nov. is described from the right ventricles and pulmonary arteries of the red kangaroo, *Macropus rufus* (Desmarest, 1822), from the Pilbara region of Western Australia. It is the largest and most robust species of *Breinlia (Breinlia)* known to date and is distinguished from all other species by the close similarity in size between males and females, the presence of a filamentous membrane surrounding the distal tip of the left spicule and the presence of a pair of caudal glands secreting a material which adheres to the caudal end of some fixed specimens, masking external cuticular features. The new species is most similar to *B. (B.) trichosuri*, *B. (B.) boltoni* and *B. (B.) mundayi* but distinguished from all 3 by its much greater size and the absence of internolateral cephalic papillae.

KEY WORDS: Nematoda, marsupials, kangaroo, *Breinlia*, new species, *Macropus*.

Introduction

The genus *Breinlia* Yorke and Maplestone, 1926, subgenus *Breinlia* represents a group of parasitic filarioid nematodes occurring in the body cavities, subcutaneously and in the vascular system of murid and sciurid rodents and primates in Asia (Chabaud and Bain, 1976; Bain *et al.*, 1983), in dasyurid, peramelid, petaurid, pseudocheirid, phalangerid, phascolarctid, potoroid and macropodid marsupials in Australia and Papua New Guinea (Spratt and Varughese, 1975; Spratt *et al.* 1991), and in native murid rodents in northwestern Western Australia (Beveridge and Spratt, 1996). Microfilariae occur in the peripheral circulation and in the four life cycles that have been investigated (*B. booliati* Singh and Ho, 1973, *B. manningi* Bain, Petit, Ratanaworabhan, Yenbutra and Chabaud, 1981, and *B. sergenti* Mathis and Léger, 1909 in Southeast Asia and *B. macropi* Spratt and Varughese, 1975 in Australia) mosquitoes act as intermediate hosts (Ho *et al.*, 1973; Bain *et al.*, 1981; Ramachandran and Dunn, 1968; Zaman and Chellappah, 1968; Beveridge and Spratt, 1996). There are many species of *Breinlia* but only one, *B. woerlei* (Spratt and Varughese, 1975) Bain, Baker and Chabaud, 1983 occurs in the heart. However, in the filarioid genus, *Dirofilaria* Railliet and Henry, 1911 a number of species occur in the heart, the best known example in Australia being the dog

heartworm, *D. immitis* (Leidy, 1856). An inspector in a wild meat export abattoir in Perth encountered large filarioid nematodes in the right ventricles and pulmonary arteries (Fig. 1) of red kangaroos, *Macropus rufus*, from the Pilbara region of Western Australia, which represents a new species of *Breinlia (Breinlia)* described below.

Materials and Methods

Nematodes were fixed at room temperature in 70% ethanol with 5% glycerine and cleared in lactophenol for examination. *En face* preparations of the cephalic extremity were prepared by the method of Anderson (1958). The same glycerine jelly hanging-drop

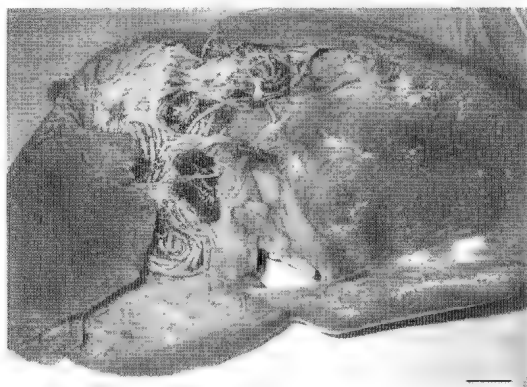
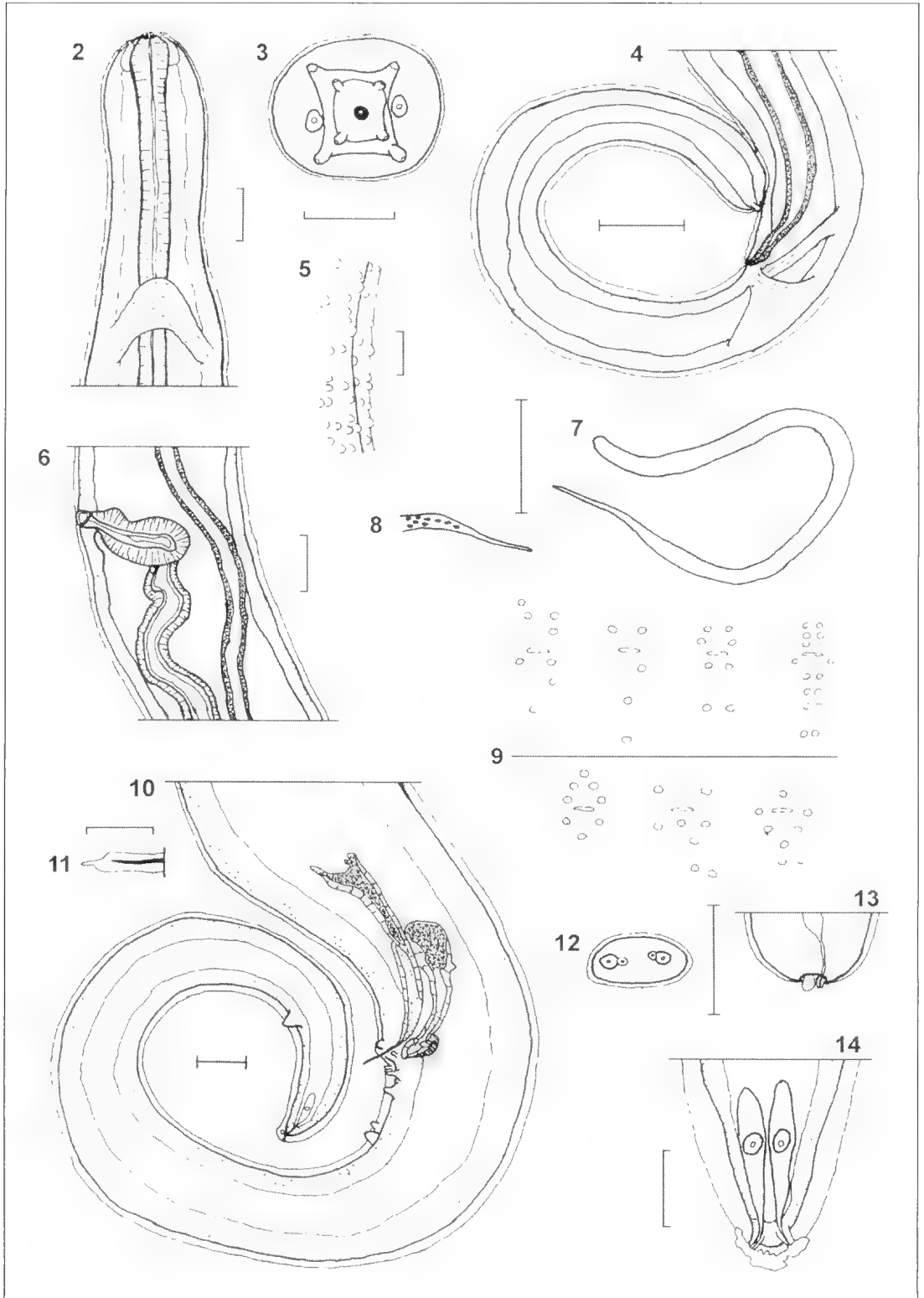


Fig. 1. *Breinlia (Breinlia) ventricola* sp. nov. in right ventricle of red kangaroo, *Macropus rufus*, scale bar 10 mm.

* CSIRO Sustainable Ecosystems, GPO Box 284, Canberra ACT 2601.

[†] School of Veterinary and Biomedical Sciences, Murdoch University, Perth, WA 6150.



technique was used to study the posterior ends of some males and females.

Measurements of 9 adult males and 9 adult females are presented in millimetres as the mean followed by the range in parentheses, those of 10 microfilariae from the *vagina uterina* of female worms are in micrometres. Drawings were made with the aid of a drawing tube. Type-specimens are deposited in the South Australian Museum (SAM) Australian Helminth Collection (AHC), Adelaide and the Queensland Museum (QM), Brisbane. Additional material is in the Western Australia Museum (WAM), in CSIRO Sustainable Ecosystems and in the School of Veterinary and Biomedical Sciences, Murdoch University

***Breinlia (Breinlia) ventricola* sp. nov.**
(FIGS 2-14)

Material examined:

Holotype

♂ from right ventricle of *Macropus rufus* (Desmarest, 1822), Mindaroo Station, 50 km southwest of Onslow (21° 41' S, 115° 08' E) Western Australia, coll. F. Stephens, 9 May, 2002, SAM AHC [IDW]32174.

Allotype

♀ same data, SAM AHC [IDW]32175.

Paratypes

4♂♂, from right ventricle and pulmonary arteries of *M. rufus*, Warrawagina Station (20° 51' S, 120° 41' E) Western Australia, coll. F. Stephens, 4 June, 2002, SAM AHC 32176, 4♀♀ same data AHC 32177, 4♂♂ same data, QM G222333-222336, 4♀♀ same data, QM G222337-222340.

Other material examined

Fragments of specimens from type localities in the Parasite Collection of CSIRO Sustainable Ecosystems, Canberra, W/L HC# N5259; 1♀ from *M. rufus* near Mt. Augustus (24° 19' S, 116° 50' E) in WAM V4382, 2♀♀ same data in Department of Veterinary Biology and Biomedical Sciences, Murdoch University, Perth, X02/07.

Prevalence

Observed in 19 of 550 (3.5%) red kangaroos examined.

Site in host

Right ventricle and pulmonary arteries.

Etymology

The suffix -icola means "inhabiting" and the specific epithet reflects the location of the nematodes in the right ventricle of the host.

Description

Long, robust nematodes with attenuated anterior and helically coiled posterior extremities. Oral opening small, round, not bounded by prominent refractile membrane. Cephalic extremity large, oval. Four pairs of submedian papillae arranged in outer circle of 4 large and inner circle of 4 slightly smaller papillae. Rectangular cuticular peribuccal field present, appearing as slight elevation of cuticle joining bases of papillae of inner circle. Distance between papillae on lateral surface greater than on dorsal and ventral surfaces. Second cuticular peribuccal field present, rectangular in shape, formed by slight elevation of cuticle joining bases of papillae of outer circle. Distance between papillae on lateral surfaces greater than on dorsal and ventral surfaces. Internolateral papillae absent. Amphids lateral, large but not raised, opening at level of outer circle of papillae; amphidial pouches large. Buccal capsule minute, narrow, with delicate wall. Small, refractile pre-pharyngeal ring present. Oesophagus divided into short anterior muscular and long posterior glandular regions. Excretory pore not observed. Cuticle with conspicuous transverse striations. Refractile cuticular bosses observed on ventral surface of males only. Lateral cords and hypodermal nuclei inconspicuous. Lateral alae absent. Deirids not observed.

Male

Total length 195 (180–220); maximum width 0.84 (0.76–0.89) in mid-body region; nerve ring 0.40 (0.37–0.42) from anterior extremity; muscular oesophagus 0.79 (0.71–0.90) long, glandular

Figs 2-14. *Breinlia (Breinlia) ventricola* sp. nov. 2. Anterior end female, dorsal view. 3. Cephalic extremity female, apical view. 4. Female tail, lateral view. 5. Cuticular rugosities on ventral surface of male in posterior one-third of body. 6. Female vulva and vagina, lateral view. 7. Microfilaria. 8. Tail of microfilaria showing terminal nuclei. 9. Diagrammatic representation of seven patterns of distribution of cloacal papillae in males. 10. Male tail, lateral view. 11. Distal tip of left spicule. 12. Caudal end of male showing pair of lateroventral lappets and medial openings of ducts of caudal glands, apical view. 13. Caudal end of male, latero-ventral view. 14. Caudal end of male with caudal glands and secretion on cuticle, ventral view. Scale bars 0.05 mm 4, 6, 7, 11, 12, 13; 0.1 mm 1, 2, 9, 10; 0.2 mm 3, 5.

oesophagus 2.1 (1.9 – 2.4) long. Spicules unequal, dissimilar, heavily sclerotized, left spicule 0.59 (0.56 – 0.61) long, calamus 0.26 (0.25 – 0.28), lamina 0.16 (0.15 – 0.17), filament 0.17 (0.16 – 0.19) terminating in fine sclerotized rod surrounded by filamentous membrane; right spicule 0.33 (0.32 – 0.34) long, with calciform, spatulate distal extremity. Gubernaculum present, 0.06 (0.06 – 0.07) long, U-shaped in ventral view with deep lateral walls appearing to wrap around lateral edges of right spicule. Tail helically coiled, 1.2 long, terminating in two large lateroventral lappets located close to one another. Two large caudal glands present, opening adjacent and median to lappets. Some males with material secreted from glands adhering to caudal cuticle and masking view of external features of caudal end. Cloacal papillae highly variable in number, ranging from 6 – 16 with 8 the most frequently occurring number, and in pre- and post-cloacal positions, the majority clustered around cloacal aperture; aperture slightly elevated. Some males with one or two subterminal medio-ventral papillae, some with a subterminal medio-dorsal papilla. Cuticle with longitudinally elongate, refractile, cuticular bosses on ventral surface, commencing posterior to oesophago-intestinal junction and terminating approximately 3 mm from cloacal aperture.

Female

Total length 233 (205 – 260); maximum width 1.60 (1.30 – 2.20) in mid-body region; nerve ring 0.40 (0.34 – 0.45) from anterior extremity; muscular oesophagus 0.75 (0.63 – 0.87) long, glandular oesophagus 1.50 (0.91 – 2.40) long. Vulva well posterior to oesophago-intestinal junction, 7.20 (5.20 – 9.50) from anterior extremity; vagina 2.40 (1.90 – 2.70) long, thick-walled, muscular. Tail helically coiled, tapering characteristically on the dorsal surface and terminating in two large lateroventral lappets located close to one another. Two large caudal glands present, opening adjacent and median to lateroventral lappets. Some females with material secreted from glands adhering to caudal cuticle and masking view of external features of caudal end. Phasmids not observed. Cuticular bosses absent.

Microfilariae from vagina uterina

Body length 265 (263 – 267); maximum width 6 in mid-body region; nerve ring 51 (49 – 53) and excretory vesicle 79 (78 – 80) from anterior extremity; anal vesicle 208 (205 – 210). Body tapering behind vesicle; nuclear column terminating in single row of 3 small, elongate nuclei; tail filamentous. Distance from last nucleus to tail tip 26 (25 – 28). Cuticle with conspicuous transverse striations. Microfilaria unsheathed, presumed to occur in blood of host.

Discussion

Two subgenera of *Breinlia* were defined by Anderson and Bain (1976), *B. (Breinlia)* Yorke and Maplestone, 1926 (not Chabaud and Bain, 1976 as listed by Anderson and Bain, 1976) recognised by spicules unequal in length, the presence of a divided oesophagus and the presence of a gubernaculum, and *B. (Johnstonema)* (Yeh, 1957) recognised by spicules equal or subequal in length, the presence of an oesophagus not clearly divided in females, the presence of external labial papillae arranged in the form of a dorsoventrally expanded rectangle, a buccal cavity with thin walls and the absence of a gubernaculum. However, the morphology of the spicules with the left spicule clearly divided into calamus, lamina and filament and the right with a calciform, spatulate distal extremity is more typical of the subgenus *Breinlia* than of *Johnstonema* and on this basis particularly, we have placed this species therein.

Breinlia (B.) ventricola is distinguished from all other known species of *B. (Breinlia)* (n = 19) and *B. (Johnstonema)* (n = 4) by its great length and breadth (males twice as long and broad and females one eighth as long and nearly three times as broad as largest species known previously), the close similarity in size between males and females, the presence of a filamentous membrane surrounding the distal tip of the left spicule and the presence of a pair of caudal glands in male and female worms secreting a material which adheres to the caudal end of some fixed specimens masking external cuticular features. In addition, the spicules in species of *B. (Johnstonema)* are stout, subequal and the left spicule is not divided into calamus, lamina and filament. The new species most closely resembles *Breinlia (B.) trichosuri* (Breinl, 1913) from the peritoneal cavity of the common brushtail possum, *Trichosurus vulpecula* (Kerr, 1792) in Queensland, *B. (B.) mundayi* Spratt and Varughese, 1975 from the pericardium of the red-necked wallaby, *Macropus rufogriseus* (Desmarest, 1817), in Tasmania and *B. (B.) boltoni* Spratt and Varughese, 1975) from the peritoneal cavity of the agile wallaby, *M. agilis* (Gould, 1842), from northern Australia. *Breinlia (B.) ventricola* is distinguished from all three by its much greater size and the absence of a pair of internolateral cephalic papillae. Previously, *B. (B.) macropi* from the quokka, *Setonix brachyurus* (Quoy and Gaimard, 1830), was the only filaroid nematode known from marsupials in Western Australia.

The two subgenera of *Breinlia* occurring in Australia are most common in macropodoid marsupials with 14 species previously described from the pleural and peritoneal cavities, pericardial sac, right ventricle and subcutis (Spratt and

Varughese, 1975) in addition to a number of undescribed species (Spratt *et al.* 1991). Additional species of the subgenus occur in dasyurid, peramelid, petaurid, pseudocheirid, phalangerid and phascolarctid marsupials. The subgenera have been interpreted as a group of Australian parasites, having migrated relatively recently from Asia in murid rodents and subsequently radiating widely in marsupials (Bain *et al.*, 1983). Species of the subgenus *Breinlia* are known to occur in six species of "old endemic" murid rodents but only in the Kimberley region of Western Australia, all morphologically indistinguishable from species described from pseudocheirid and macropodid marsupials. No species of the subgenus *Johnstonema* are known from murid rodents in Australia. In Australian marsupial hosts, species of both subgenera appear relatively host specific, but those occurring in macropodoids, especially in the family Macropodidae, exhibit the least host specificity. Consequently, one might expect to encounter *B. (B.) ventricola* in other species, particularly of the larger kangaroos and wallaroos. However, it is surprising that such a large nematode has not been encountered previously, particularly

given the large export trade in kangaroo meat. This suggests that the species may not only be specific to the red kangaroo but also may be limited to the geographic region of northwestern Western Australia.

It is expected that many aspects of pathology seen in canine dirofilariasis would occur in red kangaroos infected with *B. ventricola*, because *Dirofilaria immitis* is similar in size and is found in the same sites. Dirofilariasis is characterised by pulmonary hypertension caused primarily by an intense tissue reaction (Knight, 1977). Heavy infections would also be expected to result in impaired heart valve function and physical blockage (Soulsby, 1982). Exercise intolerance is a feature of dirofilariasis and would be likely to result in greater susceptibility to predation in red kangaroos infected with *B. ventricola*.

Acknowledgements

Thanks are due to Fran Stephens for her efforts in collecting and forwarding the material for study. Ian Beveridge and Hugh Jones offered valuable comments on an earlier draft of the manuscript.

References

- ANDERSON, R. C. (1958) Méthode pour l'examen des nématodes en vue apical. *Ann. Parasitol. hum. comp.* **33**, 171-172.
- & BAIN, O. (1976) Keys to the genera of the Order Spirurida. Part 3. Diplotriaenoidea, Aprocotoidea and Filarioidea. No. 3. pp. 59-116 In: Anderson R.C., Chabaud A.G. & Willmott S. (Eds.) "CIII Keys to the Nematode Parasites of Vertebrates" (Commonwealth Agricultural Bureaux, Farnham Royal, Bucks, England).
- BAIN, O., BAKER, M. & CHABAUD, A. G. (1982 issued 1983) Nouvelles données sur la lignée *Dipetalonema* (Filarioidea: Nematoda). *Ann. Parasitol. hum. comp.* **57**, 593-620.
- , PETIT, G., RAJANAWORABHAN, N., YINBUTRA, S. & CHABAUD, A. G. (1981) Une nouvelle filaire d'écureuil en Thaïlande, *Breinlia (B.) manningi* n. sp., et son développement chez *Aedes*. *Ann. Parasitol. hum. comp.* **56**, 193-201.
- BEVERIDGE, I. & SPRATT, D. M. (1996) The helminth fauna of Australasian marsupials: origins and evolutionary biology. *Adv. Parasitol.* **37**, 135-254.
- CHABAUD, A. G. & BAIN, O. (1976) La lignée *Dipetalonema*. Nouvel essai de classification. *Ann. Parasitol. hum. comp.* **51**, 365-397.
- HO, B. C., SINGH, M. & LIM B. L. (1973) Observations on the development of a new filaria (*Breinlia booliati* Singh and Ho, 1973) of a rat *Rattus sabanus* in the mosquito *Aedes togoi*. *J. Helminthol.* **47**, 135-140.
- KNIGHT, D. H. (1977). Heartworm heart disease. *Adv. vet. Sci. comp. Med.* **21**, 107-149.
- RAMACHANDRAN, C. P. & DUNN, F. L. (1968) The development of *Breinlia sergenti* (Dipetalonematidae) in *Aedes* mosquitoes. *Ann. trop. Med. Parasitol.* **62**, 441-449.
- SOULSBY, E. J. L. 1982. "Helminths, Arthropods and Protozoa of Domesticated Animals" 7th ed. (Baillière Tindall, London).
- SPRATT, D. M. & VARUGHESE, G. (1975) A taxonomic revision of filarioid nematodes from Australasian marsupials. *Aust. J. Zool. Suppl. Ser.* **35**, 1-99.
- , BEVERIDGE, I. & WALTER, E. L. (1991) A catalogue of Australasian monotremes and marsupials and their recorded helminth parasites. *Rec. S. Aust. Mus., Monogr. Ser.* No. **1**, 1-105.
- ZAMAN, V. & CHELLAPPAH W. T. (1968) Studies on vector susceptibility and larval morphology of a filaria of the slow loris, *Nycticebus coucang*. *Ann. trop. Med. Parasitol.* **62**, 450-454.

BLACK NODDIES (ANOUS MINUTUS) AND WEDGE-TAILED SHEARWATERS (PUFFINUS PACIFICUS) AS POTENTIAL HOSTS FOR FUNGI INVADING SEA TURTLE NESTS AT HERON ISLAND, QUEENSLAND

BY A. D. PHILLOTT† & S. A. M. ELSMORE**

Summary

Phillott, A. D. (200) Black Noddies (*Anous minutus*) and Wedge-tailed Shearwaters (*Puffinus pacificus*) as Potential Hosts for Fungi Invading Sea Turtle Nests at Heron Island, Queensland. Trans. R. Soc. S. Aust. 128(1), 73-76, 31 May, 2004.

Black noddies (*Anous minutus*) and wedge-tailed shearwaters (*Puffinus pacificus*) on Heron Island (Capricorn Group, Queensland) were surveyed to determine if they harboured fungi that had been implicated in sea turtle egg mortality in situ. Isolated from the cloacal exterior of these seabirds were *Penicillium citrinum*, *Fusarium semitectum*, *F. trichothecioides*, *Aspergillus unguis*, *Aspergillus candidus*, *Acremonium* sp., *Alternaria* sp. and *Drechslera* sp. These isolates are common soil or plant fungi and their most likely origin is therefore the nest or burrow material. None of these species have been isolated from sea turtle eggs that failed to hatch.

Key Words: Seabird, fungi, sea turtles.

BLACK NODDIES (*ANOUS MINUTUS*) AND WEDGE-TAILED SHEARWATERS (*PUFFINUS PACIFICUS*) AS POTENTIAL HOSTS FOR FUNGI INVADING SEA TURTLE NESTS AT HERON ISLAND, QUEENSLAND.

by A. D. PHILLOTT*† & S. A. M. ELSMORE*

Summary

PHILLOTT, A. D. (2000) Black Noddies (*Anous minutus*) and Wedge-tailed Shearwaters (*Puffinus pacificus*) as Potential Hosts for Fungi Invading Sea Turtle Nests at Heron Island, Queensland. *Trans. R. Soc. S. Aust.* 128(1), 73-76, 31 May, 2004.

Black noddies (*Anous minutus*) and wedge-tailed shearwaters (*Puffinus pacificus*) on Heron Island (Capricorn Group, Queensland) were surveyed to determine if they harboured fungi that had been implicated in sea turtle egg mortality *in situ*. Isolated from the cloacal exterior of these seabirds were *Penicillium citrinum*, *Fusarium semitectum*, *F. trichothecioides*, *Aspergillus unguis*, *Aspergillus candidus*, *Acremonium* sp., *Alternaria* sp. and *Drechlera* sp. These isolates are common soil or plant fungi and their most likely origin is therefore the nest or burrow material. None of these species have been isolated from sea turtle eggs that failed to hatch.

KEY WORDS: Seabirds, fungi, sea turtles.

Introduction

Heron Island (23° 26' S, 151° 55' E) is a small coral cay of the Capricorn Group in the southern Great Barrier Reef, lying approximately 80km off the Queensland coast, north-east of Gladstone. The island is dominated by a central forest of *Pisonia grandis* and common stands of *Ficus opposita* and *Pandanus* sp. Exposed fringing vegetation consists of *Argusia argentea*, *Casuarina equisetifolia*, *Cordia subcordata* and *Pandanus* sp. Fosberg and Thorne (1961), Gillham (1961), Cribb (1969, 1976), Chaloupka and Domm (1986) and Rogers (1989) present descriptive lists of vascular plants from the island.

The Capricorn Group of islands have four of the major colonies of black noddies, *Anous minutus*, in the Great Barrier Reef and the largest breeding population of wedge-tailed shearwaters, *Puffinus pacificus*, in the world (Hill *et al.* 1995). Colonies of both species at Heron Island have been subject to intense surveillance.

Black noddies reside on the island year round. Breeding occurs between October and March with a peak in November/December. A single egg is laid (Kikkawa 1970) in rough nests constructed from excreta and shed *P. grandis* leaves (Barnes and Hill 1989; Hill and Rosier 1989). The majority of nesting occurs in the *P. grandis* forest, with correlations between bird density and vegetation species and physiognomy (Shipway 1969; Dale *et al.* 1984; Hulsman *et al.* 1984; Barnes and Hill 1989; Ogden 1979, 1993).

Numbers of black noddies on Heron Island have been extensively documented (Campbell and White 1910; MacGillivray 1928; Cooper 1948; Shipway 1969; Kikkawa 1970; Bingham 1977; Ogden 1979; Hulsman 1983, 1984; Barnes and Hill 1989; Ogden 1993; Hill *et al.* 1997). From 53 nests in 1910 (Kikkawa 1970), the population increased to 63,000 ±7,000 pairs in 1992 (Ogden 1993). Hence there has been an almost geometrical increase in the last 75 years (Barnes and Hill 1989) of approximately 7% per annum (Ogden 1993). The rate of increase predicted 116,615 breeding pairs by "the turn of the century" (Ogden 1993), though high adult mortality in 1997 due to lack of prey (P. O'Neill, pers.comm.) resulted in reduced numbers over the past years (Phillott, pers.ob.). Population growth has been accompanied by an expansion of the nesting area into areas inhabited by humans and the coastal woodlands since and an increase in the number of nests per tree (Barnes and Hill 1989).

The migratory wedge-tailed shearwaters arrive at Heron Island in October (Campbell and White 1910; Cooper 1948; Moulton 1961; Gross *et al.* 1963; Kikkawa 1970; Bingham 1977; Ogden 1979). Nesting commences between mid-November and mid-December (Dyer and Carter 1997) and peaks in late-December (Gross *et al.* 1963). A single egg (Dyer and Hill 1990) is incubated in a burrow (Hill and Rosier 1989; Dyer and Hill 1990) or in protected hollows on the ground among tree roots (Dyer and Hill 1990). Adults and fledglings depart the island by May-June (Miles 1964; Kikkawa 1970).

Nesting by wedge-tailed shearwaters on Heron Island has been thoroughly described (MacGillivray 1928; Shipway 1969; Kikkawa 1970; Ogden 1979; Hulsman 1983, 1984; Hill and Barnes 1989; Ogden 1994; Carter *et al.* 1996; Hill *et al.* 1996). Though

* School of Biological and Environmental Sciences, Central Queensland University, Rockhampton QLD 4702.

† Corresponding author. Email: a.phillott@cqu.edu.au.

TABLE 1. Occurrence of Fungi in Seabird Cloacal Swabs.

Fungi	Occurrence of Fungi (%)	
	<i>A. minutus</i> (n=20)	<i>P. pacificus</i> (n=20)
<i>P. citrinum</i>	95	90
<i>F. semitectum</i>	10	10
<i>F. trichothecioides</i>	0	5
<i>A. unguis</i>	5	0
<i>A. candidus</i>	5	0
<i>Acremonium</i> sp.	0	5
<i>Alternaria</i> sp.	0	5
<i>Drechslera</i> sp.	0	5

the literature appears to report an increasing population from 8,300 burrows in 1965 (Shipway 1969) to 13,381±1,556 in 1996 (Hill *et al.* 1996). Dyer *et al.* (1995) corrected for different sampling methodology and deduced a mean of approximately 15,000 active burrows over the past 35 years.

Within the southern Great Barrier Reef, green sea turtles, *Chelonia mydas*, nest almost exclusively on coral cays such as Heron Island, while the Capricorn Group is the major nesting area for loggerhead sea turtles, *Caretta caretta*, in the South Pacific Ocean (Limpus *et al.* 1983). The fungi *Fusarium oxysporum*, *Fusarium solani* and *Pseudallescheria boydii* have been isolated from the exterior of green and loggerhead sea turtle eggs at Heron Island that failed to hatch (Phillott *et al.* 2001; Phillott *et al.* 2004). Fungi within turtle nests have been implicated with variation in egg mortality between coral cays (Heron Island and the adjacent Wreck Island, 23° 20' S, 151° 57' E), and the mainland (Limpus *et al.* 1983; Phillott 2002).

F. oxysporum and *F. solani* have been detected in wild and domestic bird nests (Mazen *et al.* 1994), and *F. oxysporum* has been isolated from feather samples (Hubalek *et al.* 1995). They are known also as cellulolytic fungi (Mazen *et al.* 1994). Therefore, it is possible the substantial seabird colonies of Heron Island may function as potential reservoirs of fungi invading sea turtle nests.

Materials and Methods

The cloacal exteriors of twenty each black noddies and wedge-tailed shearwaters were individually swabbed to compare mycobiota with that isolated from failed sea turtle eggs. Adult noddies were approached while on the nest, briefly removed, swabbed and replaced. Animals with eggs or young chicks were not sampled. Shearwaters were captured by hand during the nightly courtship or pre-dawn congregations prior to leaving the island for feeding. Swabbing occurred at the point of capture and animals were released immediately.

Swabs (MW170 TRANSTUBE®, Amies Clear

Transport Media) were refrigerated at 3 – 5°C prior to incubation. Fungi were incubated on specific media and identified according to Booth (1971), Ellis (1971), Pitt (1979), Carmichael *et al.* (1980) and Klich and Pitt (1988).

Results

All 20 of the *P. pacificus* and 19 of the 20 *A. minutus* swabs were positive for cloacal mycobiota. Isolates were *Penicillium citrinum*, *Fusarium semitectum*, *F. trichothecioides*, *Aspergillus unguis*, *Aspergillus candidus*, *Acremonium* sp., *Alternaria* sp. and *Drechslera* sp. (see Table 1). Most swabs produced monocultures of *P. citrinum* (80% *A. minutus*; 75% *P. pacificus*) or *F. semitectum* (5% *P. pacificus*), however mixed cultures of *P. citrinum* + *F. semitectum* (10% *A. minutus*; 10% *P. pacificus*), *P. citrinum* + *F. trichothecioides* (5% *P. pacificus*), *P. citrinum* + *Drechslera* sp. (5% *P. pacificus*), *P. citrinum* + *Aspergillus candidus* + *Aspergillus unguis* (5% *A. minutus*) and *Alternaria* sp. + *Acremonium* sp. (5% *P. pacificus*) were also obtained.

Discussion

All of the genera isolated from seabirds are commonly associated with soil or agricultural crops (Booth 1971; Ellis 1971; Pitt 1979; Carmichael *et al.* 1980; Klich and Pitt 1988) and some (*Acremonium*, *Alternaria*, *Aspergillus*, *Fusarium*, *Penicillium*) are known to be cellulolytic fungi from birds nests (Mazen *et al.* 1994). None are true coprophiles (see Webster 1970) or keratinophiles (Pugh and Evans 1970; Rees 1977), although *F. semitectum* has been isolated from the keratinaceous scutes of a tortoise carapace (Rose *et al.* 2001). Therefore, the most likely source of the isolates is from the nesting material or the burrow substrate. None are known invaders of sea turtle eggs (see Phillott *et al.* 2001; Phillott *et al.* 2004).

While the seabirds of Heron Island do not appear to be harbouring fungi known to invade sea turtle eggs, it is possible they may play an accessory role in maintaining resident soil microbiota. Staunton Smith and Johnson (1995) calculated a guano deposition of approximately 107t from *A. minutus* and approximately 22t from *P. pacificus* on Heron Island in 1992. Total annual deposition of guano is expected to contain 9.4t of nitrogen and 1.9t phosphorus. While much of the nitrogen is leached by the high rainfall (Heatwole *et al.* 1981), phosphorus is expected to be incorporated into the soil and is important in maintaining island vegetation (Allaway and Ashford 1984). Increased soil nutrients may also assist in maintaining a high microbial load. The relationship between phosphorus levels and soil

mycobiota of Queensland turtle rookeries is under further investigation.

Acknowledgments

This work was conducted under the Queensland Parks and Wildlife Service Scientific Purposes

Permit No. C6/000114/99/SAB and Central Queensland University Ethical Clearance Certificate No. 99/11-82. K. Coufal assisted with seabird capture and handling. Dr. K. M. Harrower assisted with identification of the *Drechslera*, *Acremonium* and *Alternaria* sp. Dr. C. J. Parmenter reviewed a copy of the manuscript.

References

- ALLAWAY, W. G. & ASHFORD, A. E. R. (1984) Nutrient input by seabirds to the forest on a coral island of the Great Barrier Reef. *Mar. Ecol. Prog. Ser.* **19**, 297-298.
- BARNES, A. & HILL, G. J. E. (1989) Census and distribution of black noddy *Anous minutus* nests on Heron Island, November 1985. *Emu* **89**, 129-134.
- BINGHAM, P. (1977) Birds of Heron Island, Queensland October 4-11, 1975. *Aust. Bird Watch.* **7**, 99-100.
- BOOTH, C. (1971) "The Genus *Fusarium*" (Commonwealth Mycological Institute, Kew).
- CAMPBELL, A. J. & WHITE, S. A. (1910) Birds identified on the Capricorn Group during expedition of R.A.O.U., 8th to 17th October, 1910. *Emu* **10**, 195-204.
- CARMICHAEL, J. W., KENDRICK, W. B., CONNERS, I. L. & SIGLER, L. (1980) "Genera of Hyphomycetes" (The University of Alberta Press, Edmonton).
- CARTER, J. L., HILL, G. J. E. & DYER, P. K. (1996) Breeding cycle of wedge-tailed shearwaters *Puffinus pacificus* at Heron Island, Great Barrier Reef. *Emu* **96**, 195-198.
- CHALOUPEK, M. Y. & DOMM, S. B. (1986) Role of anthropochory in the invasion of coral cays by alien flora. *Ecology* **67**, 1536-1547.
- COOPER, R. P. (1948) Birds of the Capricorns - Great Barrier Reef. *Emu* **49**, 107-126.
- CRIBB, A. B. (1969) The Pisonia. *Qld. Nat.* **19**, 100-114.
- _____ (1976) Changes in the terrestrial flora of Heron Island. *Qld. Nat.* **21**, 110-112.
- DALE, P., HULSMAN, K., JAHINKE, B. R. & DALE, M. (1984) Vegetation and nesting preferences of black noddies at Masthead Island, Great Barrier Reef. I Patterns at the macro-scale. *Aust. J. Ecol.* **9**, 335-341.
- DYER, P. K. & CARTER, J. L. (1997) Synchronous breeding: wedge-tailed shearwaters *Puffinus pacificus* in eastern Australia. *Emu* **97**, 305-309.
- _____ & HILL, G. J. E. (1990) Nearest neighbour analysis and wedge-tailed shearwater burrow patterns on Heron and Masthead Islands, Great Barrier Reef. *Aust. Geo. Stud.* **28**, 51-61.
- _____ , HILL, G. J. E. & BARNES, A. (1995) Three decades of burrow estimates for wedge-tailed shearwaters on the Capricorn Group. *Emu* **95**, 272-279.
- ELLIS, M. B. (1971) "Dematiaceous Hyphomycetes" (Commonwealth Mycological Institute, Kew).
- FOSBERG, F. R. & THORNE, R. F. (1961) Description of Heron Island. *Atoll Res. Bull.* **82**, 5-13.
- GILLHAM, M. E. (1961) Coral cay vegetation Heron Island, Great Barrier Reef. *Proc. Roy. Soc. Qld.* **73**, 79-92.
- GROSS, A. O., MOUTON, J. M. & HUNTINGTON, C. E. (1963) Notes on the wedge-tailed shearwater at Heron Island, Great Barrier Reef, Australia. *Atoll Res. Bull.* **99**, 1-13.
- HEATWOLE, H., DONE, T. & CAMERON, E. (1981) "Community Ecology of a Coral Cay" (Junk, The Hague).
- HILL, G. & ROSIER, J. (1989) Wedgetailed shearwaters, white capped noddies and tourist development on Heron Island, Great Barrier Reef Marine Park. *J. Env. Manage.* **29**, 107-114.
- _____ , ROSIER, J. & DYER, P. (1995) Tourism development and environmental limitations at Heron Island, Great Barrier Reef: a response. *J. Env. Manage.* **45**, 91-99.
- HILL, G. J. E. & BARNES, A. (1989) Census and distribution of wedge-tailed shearwaters *Puffinus pacificus* burrows on Heron Island, November 1985. *Emu* **89**, 135-139.
- _____ , CARTER, J. L., BARNES, A., DYER, P. K. & ROSIER, D. J. (1997) The black noddy breeding population at Heron Island, Great Barrier Reef: 1985-1989. *Corella* **21**, 58-64.
- _____ , DYER, P. K., CARTER, J. L. & BARNES, T. (1996) Nesting activity, breeding success and colony size for the wedge-tailed shearwater *Puffinus pacificus* on Heron Island. *Aust. J. Ecol.* **21**, 316-323.
- HUBALEK, Z., JURICOVA, Z. & HALOUZKA, J. (1995) A survey of free-living birds as hosts and 'lessors' of microbial pathogens. *Folia Zool.* **44**, 1-11.
- HULSMAN, K. (1983) Survey of seabird colonies in the Capricornia Section of the Great Barrier Reef Marine Park. 2. Population parameters and some management options. *Research Report to the Great Barrier Reef Marine Park Authority*, Townsville.
- _____ (1984) Survey of seabird colonies in the Capricornia Section of the Great Barrier Reef Marine Park. 3. Population parameters and some management options. *Research Report to the Great Barrier Reef Marine Park Authority*, Townsville.
- _____ , DALE, P. & JAHINKE, B. R. (1984) Vegetation and nesting preferences of black noddies at Masthead Island, Great Barrier Reef. II Patterns at the micro-scale. *Aust. J. Ecol.* **9**, 343-352.
- KIKKAWA, J. (1970) Birds recorded at Heron Island. *Sunbird* **1**, 34-48.
- KILCH, M. A. & PITTI, J. I. (1988) "A Laboratory Guide to the Common *Aspergillus* Species and their Teleomorphs" (Commonwealth Scientific and Industrial Research Organisation, Division of Food Processing: North Ryde).
- LIMPUS, C. J., REED, P. & MILLER, J. D. (1983) Islands and turtles. The influence of choice of nesting beach on sex ratio pp. 397-402 In J. T. Baker, R. M. Carter, P.W. Sammarco and K. P. Stark (Eds.) "Proceedings: Inaugural Great Barrier Reef Conference, Townsville, Aug.28-Sept.2, 1983" (JCU Press, Townsville).
- MACGILLIVRAY, W. (1928) Bird-life of the Bunker and Capricorn Islands. *Emu* **27**, 230-249.
- MAZLN, M. B., MOUBASHER, A. H. & BAGY, M. M. K. (1994) Seasonal distribution of fungi in bird nests in Egypt. *Microbiol. Res.* **149**, 429-434.

- MILES, J. A. R. (1964) Notes on *Puffinus pacificus* on Heron Island, Capricorn Group. *Emu* **63**, 420-421.
- MOULTON, J. M. (1961) Some observations on the Heron Island fauna. *Atoll Res. Bull.* **82**, 15-16.
- OGDEN, J. (1979) Estimates of the population sizes of the black noddy and wedge-tailed shearwater at Heron Island in 1978. *Sunbird* **10**, 33-39.
- _____. (1993) Population increases and nesting patterns of the black noddy *Anous minutus* in *Pisonia* forest on Heron Island: observations in 1978, 1979 and 1992. *Aust. J. Ecol.* **18**, 395-403.
- _____. (1994) Population size of the wedge-tailed shearwater *Puffinus pacificus*—population in *Pisonia grandis* forest on Heron Island in 1992. *Emu* **94**, 65-68.
- PHILLOTT, A. D. (2002) Fungal Colonisation of Sea Turtle Nests in Eastern Australia. PhD Thesis, Central Queensland University, Rockhampton, Queensland, Australia.
- PHILLOTT, A. D., PARMENTER, C.J. AND LIMPUS, C.J. (2001) Mycoflora identified from the exterior of failed green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) sea turtle eggs at Heron Island, Australia. *Chel. Cons. Biol.* **4**, 170-172.
- _____, PARMENTER, C.J. AND LIMPUS, C.J. (2004) The occurrence of mycobiota in eastern Australian sea turtle nests. *Mem. Qd. Mus.* In Press.
- PITT, J. I. (1979) "The Genus *Penicillium* and its Teleomorphic States *Eupenicillium* and *Talaromyces*" (Academic Press London).
- PUGH, G. J. F. & EVANS, M. D. (1970) Keratinophilic fungi associated with birds II. Fungi isolated from feathers, nests and soils. *Trans. Brit. Mycol. Soc.* **54**, 233-240.
- REES, R. G. (1977) Keratinophilic fungi from Queensland-II. Isolations from feathers of wild birds. *Sabouraudia* **6**, 14-18.
- ROGERS, R. W. (1989) The influence of sea turtles on the terrestrial vegetation of Heron Island. Great Barrier Reef. *Proc. Roy. Soc. Qld.* **100**, 67-70.
- ROSE, F. L., KOKE, J., KOFFIN, R. & SMITH, D. (2001) Identification of the etiological agent for necrotizing scute disease in the Texas tortoise. *J. Wildl. Dis.* **37**, 223-228.
- SHIPWAY, A. K. (1969) The numbers of terns and shearwaters nesting on Heron Is. in 1965. *Emu* **69**, 108-109.
- STAUNTON SMITH, J. & JOHNSON, C. R. (1995) Nutrient input from seabirds and humans on a populated coral cay. *Mar. Ecol. Prog. Ser.* **124**, 189-200.
- WEBSTER, J. (1970) Coprophilous fungi. *Trans. Brit. Mycol. Soc.* **54**, 161-180.

Transactions of the Royal Society of South Australia Incorporated

INCORPORATING THE

Records of the
South Australian Museum

Contents

Appan, A., Bergfeld, J. & Beveridge, I. New species of parasitic nematodes from macropodid marsupials in Western Australia	77
Hammer, M. P. & Walker, K. F. A catalogue of South Australian freshwater fishes, including new records, range extensions and translocations	85
Watts, C. H. S & Humphreys, W. F. Thirteen new Dytiscidae (Coleoptera) of the genera <i>Boongurrus</i> Larson <i>Tjirtudessus</i> Watts & Humphreys and <i>Nirripiri</i> Watts & Humphreys, from underground waters in Australia	99
Watts, C. H. S. Revision of Australian <i>Scirtes</i> Illiger and <i>Ora</i> Clark (Coleoptera: Scirtidae)	131
Hodda, M. Characteristics of an Australian population of <i>Paraxonchium orthodon</i> (Loof 1964) Altherr & Loof 1969, with a note on evolution and biogeography of the subfamily Paraxonchiinae (Nematoda, Dorylaimida, Aporcelaimidae)	169
Beveridge, I. & Johnson, P. M. Cestode parasites of tree kangaroos (<i>Dendrolagus</i> spp.: Marsupialia), with the description of two new species of <i>Progamotaenia</i> (Cestoda: Anoplocephalidae)	175
Faucheux, M. J. Antennal sensilla of <i>Sabatinca sterops</i> Turner (Lepidoptera: Micropterigidae)	187
Barker, S. Twelve new species of Australian Buprestidae (Coleoptera) and new synonymy	195
Womersley, H. B. S. Additions to the Marine Algal Flora of southern Australia	205
Smith, B. P. C. & Kokkinn, M. The use of emergence as an end-point for sediment toxicity tests using the Australian chironomid <i>Chironomus maddeni</i>	213
Barton, P. S., Aberton, J. G. & Wishart, E. Spatial and temporal distribution of <i>Culex australicus</i> Dobrotworsky and Drummond and <i>Culex globocoxitus</i> Dobrotworsky (Diptera: Culicidae) at the Gippsland Lakes in eastern Victoria	219
Williams, C. R., Snell, A. E. & Kokkinn, M. J. Studies of temporal host-seeking patterns of <i>Culex Annulirostris</i> (Diptera: Culicidae): a comparison of methods and populations	225
Gibbs, S. E., Kemper, C. M., Byard, R. W. & Long, M. Deaths of killer whales (<i>Orcinus orca</i>) in South Australia and implication of human interaction	231
Hinchcliffe, J. & Conran, J. G. The Tennyson sand dunes: vegetation structure and conservation status	239
Smith, B. B. & Walker, K. F. Reproduction of common carp in South Australia, shown by young-of-the-year samples, gonadosomatic index and the histological staging of ovaries	249
<i>Brief Communications:</i>	
Souter, N. J. A comparison among three artificial substrates for aquatic macroinvertebrate sampling	259
Matthews, E. G. New synonymy and new names in Australian Tenebrionidae (Coleoptera)	261

TRANSACTIONS OF THE

**ROYAL SOCIETY
OF SOUTH AUSTRALIA**

INCORPORATED

INCORPORATING THE

Records of the
South Australian Museum

VOL. 128, PART 2

NEW SPECIES OF PARASITIC NEMATODES FROM MACROPODID MARSUPIALS IN WESTERN AUSTRALIA

By A. APPAN, J. BERGFELD* & I. BEVERIDGE**

Summary

Appan, A., Bergfeld, J. & Beveridge, I. (2004) New species of parasitic nematodes from macropodid marsupials in Western Australia. Trans. R. Soc. S. Aust. 128(2), 77-84, 30 November, 2004.

Two new species of parasitic nematodes are described from macropodid marsupials from Western Australia. *Rugopharynx setonicis* sp. nov. from the stomach of the quokka, *Setonix brachyurus*, belongs to the *Rugopharynx australis* complex, but differs from related species in the anterior position of the nerve ring, a shorter spicule length and the anterior position of the deirids. A second new species, from the oesophagus of *Macropus irma*, is described. *Cyclostrongylus irma* sp. nov. is distinguished from congeners by a buccal capsule which is wider near its anterior extremity, longer spicules and a short oesophagus. The descriptions of the two new species provide additional evidence in support of current hypotheses for the mode of evolution of the respective genera.

Key Words: Nematoda, marsupials, *Macropus*, *Setonix*, new species, *Rugopharynx*, *Cyclostrongylus*.

NEW SPECIES OF PARASITIC NEMATODES FROM MACROPODID MARSUPIALS IN WESTERN AUSTRALIA

by A. APPAN*, J. BERGFELD* & I. BEVERIDGE*

Summary

APPAN, A., BERGFELD, J. & BEVERIDGE, I. (2004) New species of parasitic nematodes from macropodid marsupials in Western Australia. *Trans. R. Soc. S. Aust.* 128(2), 77-84, 30 November, 2004.

Two new species of parasitic nematodes are described from macropodid marsupials from Western Australia. *Rugopharynx setonicis* sp. nov. from the stomach of the quokka, *Setonix brachyurus*, belongs to the *Rugopharynx australis* complex, but differs from related species in the anterior position of the nerve ring, a shorter spicule length and the anterior position of the deirids. A second new species, from the oesophagus of *Macropus irma*, is described. *Cyclostrongylus irma* sp. nov. is distinguished from congeners by a buccal capsule which is wider near its anterior extremity, longer spicules and a short oesophagus. The descriptions of the two new species provide additional evidence in support of current hypotheses for the mode of evolution of the respective genera.

KEY WORDS : Nematoda, marsupials, *Macropus*, *Setonix*, new species, *Rugopharynx*, *Cyclostrongylus*.

Introduction

Kangaroos and wallabies harbour an extremely diverse fauna of helminth parasites (Spratt *et al.* 1991), dominated numerically by species of the strongyloid subfamily Cloacininae Stossich, 1889 which occur principally in the stomachs and to a lesser extent the oesophagi of these hosts (Beveridge & Spratt 1996; Beveridge & Chilton 2001). In spite of the fact that some 36 genera and 256 species have been described thus far within the subfamily (Beveridge & Chilton 2001), substantial numbers of species remain undescribed (Spratt *et al.* 1991; Beveridge & Chilton 2001). Apart from their numerical importance and possible role in disease (Beveridge & Presidente 1978), the nematodes are also of interest due to the fact that some genera inhabit unusual sites within the gastrointestinal tract such as the oesophagus (e.g. *Cyclostrongylus* Johnston & Mawson, 1939) and in some genera, large numbers of cryptic species are present (e.g. *Rugopharynx* Mönnig, 1927), suggesting recent and rapid evolutionary expansions within the parasite genus (Beveridge & Chilton 1999, 2001). In addition, recent phylogenetic studies (Beveridge & Chilton 2001) indicate that colonization has been the major mode of diversification rather than cospeciation. Thus the nematode parasites of macropodids are of particular biological as well as of taxonomic interest.

The nematode parasites of eastern Australian macropodid species have been studied to a much greater degree than those of western Australia (see summary in Beveridge & Chilton 2001), such that

much descriptive work remains to be carried out in hosts from the latter region. In this paper, two new species of nematodes are described from Western Australian marsupials, a new species from the *Rugopharynx australis* (Mönnig, 1926) species complex, which has apparently undergone a recent and dramatic evolutionary expansion in macropodids (Beveridge & Chilton 2001) and a new species of the genus *Cyclostrongylus*, a genus which is highly unusual in occurring coiled around papillae in the oesophagus of its host.

Materials and Methods

Nematodes were collected from macropodids obtained as road-kills. Host animals, which had been frozen following collection, were thawed and stomach or oesophageal content containing nematodes was fixed in 10% formalin for transportation to the laboratory. In the laboratory, nematodes were extracted from fixed stomach content, washed in water to remove formalin and stored in 70% ethanol.

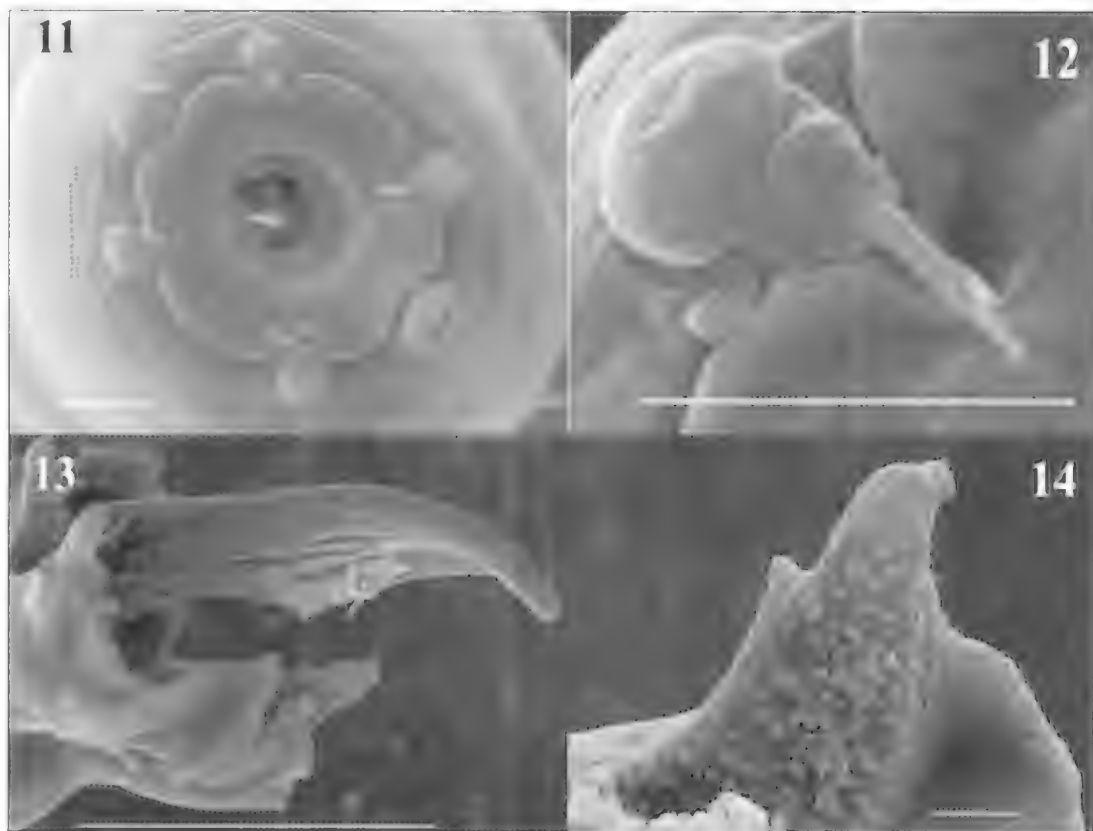
All specimens were examined after clearing in lactophenol. Drawings were made with the aid of a drawing tube attached to an Olympus BH2 microscope. Apical views of the anterior end and body sections are oriented with the dorsal aspect uppermost; extended bursae are oriented with the ventral lobes uppermost. Measurements were made with an ocular micrometer and are presented in mm as the range followed by the mean in parentheses. Morphological terminology follows Beveridge & Chilton (1999) for the description of the new species of *Rugopharynx* and Beveridge (1982) for the description of the new species of *Cyclostrongylus*.

Types of new species have been deposited in the

* Department of Veterinary Sciences, University of Melbourne, Parkville Vic. 3052



Figs 1-10. *Rugopharynx setonicis* sp. nov. from the stomach of *Setonix brachyurus*. 1. Anterior end, lateral view. 2. Buccal capsule, lateral view. 3. Transverse optical section through buccal capsule. 4. Genital cone dorsal view. 5. Apical view of cephalic extremity. 6. Spicule tip, lateral view. 7. Gubernaculum, ventral view. 8. Terminal female genitalia, lateral view. 9. Bursa, apical view. 10. Female tail, lateral view. Scale bars = 0.1 mm, 1, 8, 10; 0.01 mm, 2-7, 9. Legend : A, amphid; BC, buccal capsule; C, cementum; CC, cephalic collar; D, deirid; E, excretory pore; EB, extrabuccal support; LC, labial collar; N, nerve ring; O, ovejector; S, submedian papilla; V, vagina.



Figs 11-14. Scanning electron micrographs of *Rugopharynx setonicis* sp. nov. from the stomach of *Setonix brachyurus*. 11. Apical view of anterior end showing collars and stoma. 12. Submedian cephalic papilla armed with seta with bifurcate extremity. 13. Bursa with everted spicule tips. 14. Bosses on internal surface of lateral lobe of bursa. Scale bars – 0.1 mm, 11-13, 0.01 mm, 14.

collections of the South Australian Museum, Adelaide (SAM), the Natural History Museum, London (BMNH) and the United States National Parasite Collection (USNPC).

Several specimens of each species were examined by scanning electron microscopy (SEM). Specimens were dehydrated in an ethanol series, transferred to hexamethyldisilasane, allowed to dry, then sputter-coated with gold and examined with a Phillips 505 SEM using an accelerating voltage of 5-10KV.

Results

Rugopharynx setonicis sp. nov. (FIGS 1-14)

Types

Holotype ♂ from stomach of *Setonix brachyurus* (Quoy & Gaimard, 1830), Wellington Dam, Western Australia (33° 24' S 116° 00' E), coll. R. Brazelle, SAM 32182. Allotype ♀, same data, SAM 32183.

Paratypes: 5♂, 5♀, same data, SAM 32184; 1♂, 1♀, BMNH 2003.2.7.1-2; 1♂, 1♀, USNPC 93586.

Description

Chabertiidae (Popova, 1952); Cloacininae Stossich, 1899. Small worms; body covered with numerous fine transverse annulations. Prominent cephalic collar present (Fig. 2). Collar with paired lateral amphids on prominent elevations, and 4 conical, sub-median papillae; each papilla bearing single, medially-directed seta; setae only visible in apical preparations of head (Fig. 5); scanning electron micrographs (Fig. 12) show seta arising from bulbous expansion on medial aspect of papilla; seta bifid distally with one branch much shorter than other. Prominent, continuous labial collar internal to cephalic collar (Figs. 5, 11); collar indented medial to amphids and sub-median papillae. Stoma circular in apical views of head; labial collar continuous internally with lining of buccal capsule. Prominent extra-buccal supports present surrounding anterior extremity of buccal

capsule (Fig. 2). Buccal capsule short, thick-walled, variable in shape, longer than wide, thicker at anterior extremity with slight constriction at one sixth of length. Buccal capsule with numerous transverse striations; striations sinuous, faint, branch and anastomose frequently; near anterior extremity, striations faint and irregular; in optical transverse section, striae radially arranged (Fig. 3). Oesophageal corpus elongate, sub-cylindrical, slightly wider towards posterior extremity (Fig. 1); isthmus short, leading to elongate, clavate bulb. Deirids in anterior oesophageal region. Nerve ring encircles oesophageal corpus at $\frac{1}{3}$ length, anterior to isthmus. Excretory pore between nerve ring and isthmus (Fig. 1).

Male

Measurements of 10 specimens, types. Total length 5.30 – 6.48 (6.15); maximum width 0.28 – 0.35 (0.30); buccal capsule 0.030 – 0.040 (0.037) long by 0.015 (0.015) wide; oesophagus 0.70 – 0.85 (0.79) long; nerve ring to anterior end 0.34 – 0.40 (0.38); excretory pore to anterior end 0.40 – 0.50 (0.48); deirids to anterior end 0.09 – 0.13 (0.11). Bursa short; dorsal lobe with slight indentation in margin; dorsal lobe equal in length to lateral lobes; lateral lobes with crenulate margins with radially directed striae close to margin. Internal surfaces of ventral and lateral lobes with numerous refractile bosses; bosses overlie ventral and lateral rays, extend in marginal band along lateral lobes between postero-lateral and externo-dorsal rays (Fig. 9). Ventro-ventral and latero-ventral rays slender, apposed, reaching margin of bursa. Medio-lateral and postero-lateral rays stout, reaching margin of bursa; externo-lateral ray shorter, divergent, originates close to base of lateral trunk, slightly reflexed near distal extremity, terminating in elevation of cuticle close to margin of bursa. Externo-dorsal ray originates close to lateral trunk, stout, straight, almost reaches margin of bursa. Dorsal ray broad at origin, divides at mid-length; internal branchlets arcuate, elongate, directed posteriorly, reach margin of bursa; external branchlets arise at main bifurcation, slightly shorter than internals, recurrent, terminate in elevations of cuticle on internal surface of bursa. Genital cone prominent; anterior lip large, conical; posterior lip with pair of bilobed appendages and ring of smaller projections around base (Fig. 4). Spicules 1.00 – 1.34 (1.20) long, alate; proximal tips knobbed, shafts cylindrical, distal tips blunt with slight terminal enlargement; alae broad, diminish in width towards tip, lose striations (Fig. 6). Gubernaculum poorly sclerotised, visible in lateral views but rarely visible in dorso-ventral views (Fig. 7); cordate and paired lateral thickenings of spicule sheaths present.

Female

Measurements of 10 specimens, types. Total length

6.75 – 7.90 (7.36); maximum width 0.28 – 0.36 (0.32); buccal capsule 0.03 – 0.05 (0.04) long by 0.015 (0.015) wide; oesophagus 0.83 – 0.96 (0.89) long; nerve ring to anterior end 0.37 – 0.42 (0.39); excretory pore to anterior end 0.43 – 0.57 (0.48); deirids to anterior end 0.09 – 0.11 (0.10); tail elongate, tapering, 0.35 – 0.50 (0.44) long; vulva 0.50 – 0.62 (0.58) from posterior end, frequently surrounded by mass of cementum (Fig. 10); vagina straight, short, 0.34 – 0.55 (0.43) long; ovejector J-shaped; vestibule longitudinally disposed, differentiation between sphincters and infundibula indistinct (Fig. 8); egg ellipsoidal 0.11 – 0.14 (0.12) long by 0.05 – 0.06 (0.055) wide.

Cyclostrongylus irma sp. nov. (FIGS 15-28)

Synonyms

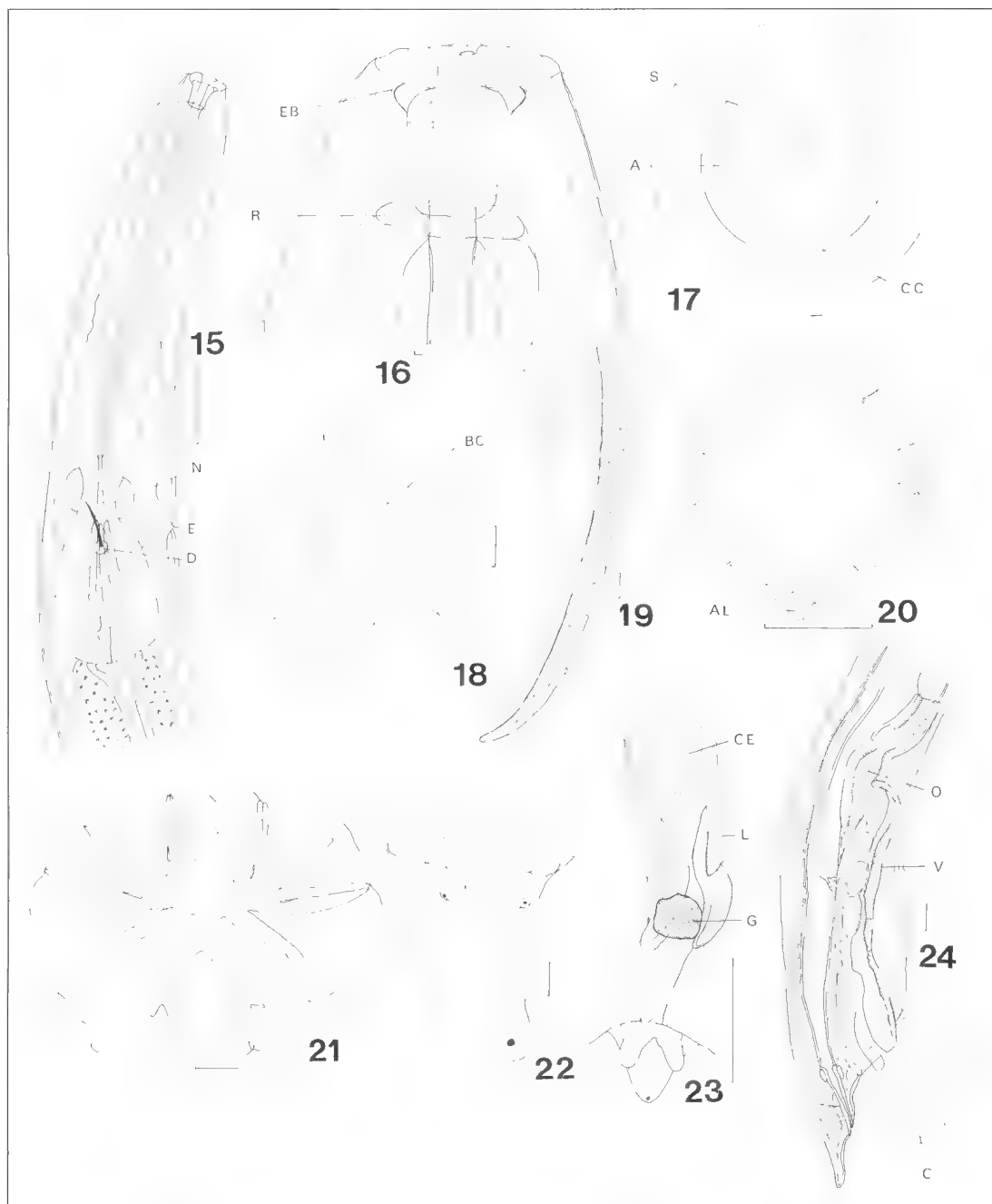
Cyclostrongylus wallabiae Johnston & Mawson, 1939 of Spratt *et al.* 1991, p. 51.

Types

Holotype ♂ from oesophagus of *Macropus irma* (Jourdan, 1837), Collie, Western Australia (33° 22' S 116° 09' E), 11.xii.2001, coll. R. Brazelle, SAM 32185. Allotype ♀, same data, SAM 32186. Paratypes: 10♂, 20♀, same data, SAM 32187; 1♂, 1♀, BMNH 2003.2.7.3-4; 1♂, 1♀, USNPC 93587. *Other material examined*: from oesophagus of *M. irma*: Western Australia: 14♂, 14♀, Perth, Feb. 1981, coll. P. Christensen (SAM 8324); 23♂, 22♀, Jandakot, April, 1982, coll. L. Jue Sue (SAM 11545).

Description

Chabertiidae (Popova, 1952); Cloacininae Stossich, 1899. Small nematodes up to 12mm long. Mid-region of bodies coiled around oesophageal papillae of host; males usually with a single coil (Fig. 25), female nematodes with 2 or more coils (Fig. 26). Body covered with numerous transverse annulations. Single triangular ala present on the ventral surface (Figs. 20, 27), extending along mid-body region. Cephalic collar distinct, with 2 slightly domed amphids and 4 domed submedian papillae. No labial crown or collar. Mouth opening and buccal capsule circular in apical view (Fig. 17) and optical cross-section respectively (Fig. 18). Buccal capsule short, thick-walled, transversely striated; all of buccal capsule thicker anteriorly; transverse striations regular, extend along entire buccal capsule (Fig. 16). Extra-buccal supports prominent. Prominent, refractile ring present between buccal capsule and oesophagus. Oesophagus short, corpus widening slightly before constriction at isthmus; ovoid oesophageal bulb with 3 sclerotised plates (Fig. 15). Excretory pore at level of deirids, latter at



Figs 15-24. *Cyclostrongylus irma* sp. nov. from the oesophagus of *Macropus irma*. 15. Anterior end, lateral view. 16. Cephalic end, lateral view. 17. Cephalic end, apical view. 18. Transverse optical section through buccal capsule. 19. Distal tip of spicule, lateral view. 20. Transverse section through mid-region of body showing ventral ala. 21. Bursa of male, apical view. 22. Genital cone, dorsal view. 23. Gubernaculum and thickenings of spicule sheath, ventral view. 24. Posterior end of female, lateral view. Scale bars = 0.1 mm, 15, 21, 23, 24, 0.01 mm, 16-20, 22. Legend: A, amphid; AL, ala; BC, buccal capsule; C, cementum; CE, central cordate thickening of spicule sheath; CC, cephalic collar; D, deirid; E, excretory pore; EB, extrabuccal support; G, gubernaculum; L, lateral thickening of spicule sheath; N, nerve ring; O, ovejector; R, post-buccal sclerotised ring; S, submedian papilla; V, vagina.

level of mid-oesophageal bulb. Nerve ring encircles oesophageal isthmus.

Male

Measurements of 10 specimens, types. Total length 8.78 – 9.84 (9.60); maximum width 0.22 – 0.28 (0.24); buccal capsule 0.035 – 0.045 (0.042) long by 0.030 (0.030) wide; oesophagus 0.65 – 0.75 (0.71) long; nerve ring 0.49 – 0.56 (0.52) from anterior end; excretory pore 0.57 – 0.69 (0.62) from anterior end; deirid 0.59 – 0.72 (0.66) from anterior end. Bursa short, lobes of equal size (Fig. 21). Separation of lobes indistinct; no striae or bosses on internal surface of bursa. Ventro-ventral and ventro-lateral rays slender, apposed, reaching margin of bursa. Lateral rays stout; medio-lateral and postero-lateral rays apposed, reaching margin of bursa; externo-lateral ray divergent, joins lateral trunk near origin, does not reach margin of bursa. Externo-dorsal ray originates close to lateral trunk, not reaching margin of bursa, curves slightly near tip. Dorsal ray bifurcates $\frac{1}{4}$ -length, each major branch with small laterally-directed branch arising more than half-way along its length; 2 major branches of the dorsal ray reaching margin of bursa. Spicules alate, 1.25 – 1.48 (1.38) long; proximal extremity knobbed; shaft cylindrical; distal tip blunt, slightly recurved (Fig. 19); ala diminishes in width towards tip, loses transverse striations. Gubernaculum approximately quadrangular in dorsoventral view (Fig. 23), 0.10 – 0.20 (0.14) long. Genital cone prominent; anterior lip large, conical; posterior lip with 2 lobe-like appendages (Fig. 22). Central cordate and lateral paired thickenings of spicule sheaths present (Fig. 23).

Female

Measurements of 10 specimens, types. Total length 9.55 – 11.58 (10.81); maximum width 0.30 – 0.34 (0.32); buccal capsule 0.040 – 0.050 (0.045) long by 0.030 – 0.040 (0.034) wide; oesophagus 0.73 – 0.84 (0.79) long; nerve ring 0.52 – 0.57 (0.55) from anterior end; excretory pore 0.61 – 0.70 (0.65) from anterior end; deirid 0.63 – 0.71 (0.68) from anterior end. Tail short, conical, 0.14 – 0.18 (0.16) long; vulva immediately anterior to anus, 0.23 – 0.36 (0.29) from posterior end, frequently surrounded by mass of cementum (Fig. 24); vagina straight, 0.08 – 0.22 (0.14) long; ovejector longitudinally disposed. Egg thin shelled, ovoid, 0.06 – 0.09 (0.08) long by 0.04 – 0.05 (0.05) wide.

Discussion

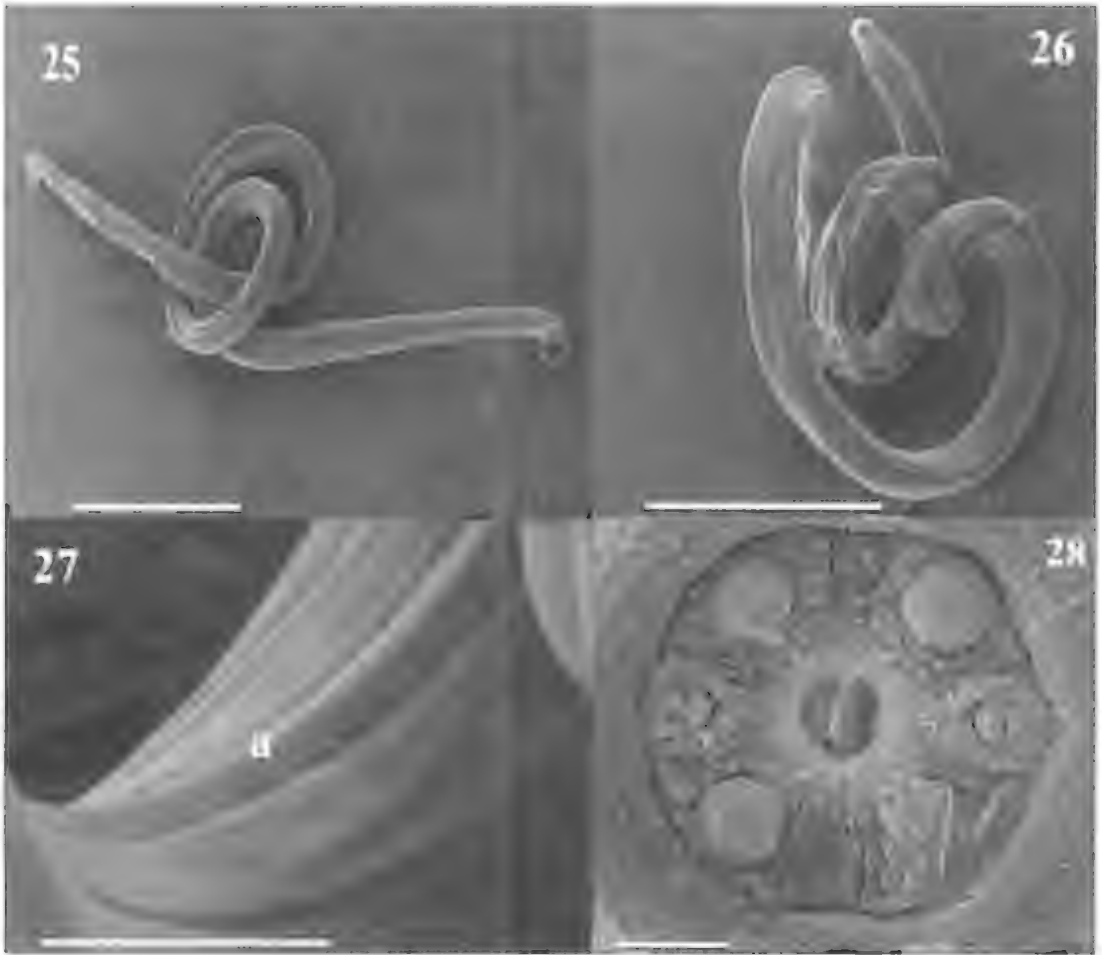
The specimens described from the stomach of *Setonix brachyurus* are allocated to the genus *Rugopharynx*, due to the presence of two pairs of

branches to the dorsal ray, a cylindrical buccal capsule and the externo-dorsal ray arising with the lateral rays, all characters of the subfamily Cloacininae. The prominent transverse striations of its buccal capsule, short oesophageal corpus and lack of petaloid or lobed labial crown elements and alae place it in the genus *Rugopharynx*. Within the genus, the sub-cylindrical buccal capsule, lacking prominent subdivisions, places it within the *Rugopharynx australis* complex (Beveridge 1982; Beveridge & Chilton 1999).

Within this complex, the specimens cannot be attributed to any of the known species (Beveridge & Chilton 1999). The nerve ring encircles the anterior part of the oesophageal corpus rather than the isthmus, hence differentiating them from all species except *R. petrogale* Beveridge & Chilton, 1999, *R. rosemariae* Beveridge & Presidente, 1978 and *R. rho* Beveridge & Chilton, 1999. The specimens described here lack the small sclerotised bosses lining the oesophagus which are characteristic of *R. rosemariae* and the length of the spicules, 1.00 – 1.34 (1.20) mm, is significantly shorter than those of *R. rosemariae* (3.85 – 4.35 mm). *R. rho* has a non-lobed buccal capsule but its spicules (1.65 – 1.92 mm) are significantly longer. *R. petrogale* has three, very weakly-developed lobes to the wall of the buccal capsule, compared with the current specimens which have the buccal capsule wall slightly thickened at its anterior extremity. In addition, the dorsal ray in *R. petrogale* is longer than the lateral rays while in the specimens described here, the rays are of similar length. The proximity of the deirids to the anterior end of the nematode also differ significantly from specimens of *R. petrogale*. For these reasons, the material described is considered to represent a new species, and is named *R. setonicis* sp. nov. as the quokka, *Setonix brachyurus*, is its only known host.

Beveridge & Chilton (2001) examined the host range of members of the *R. australis* complex and concluded that the distribution of nematode species bore no relationship to the phylogeny of the hosts. They suggested that members of this species complex may have evolved recently, due to the relatively minor morphological differences between their constituent members, and that colonization of hosts had occurred rather than co-speciation. The addition of a new member of the complex from *Setonix* is consistent with this hypothesis given the relatively basal (though uncertain) position of *Setonix* in the phylogeny of the Macropodidae (Flannery 1989).

Two genera of cloacinid nematode are known to occur coiled around the oesophageal papillae of wallabies, namely *Cyclostrongylus* Johnston & Mawson, 1929 and *Spirostrongylus* Yorke &



Figs 25-28. *Cyclostrongylus irma* sp. nov. from the oesophagus of *Macropus irma*. 25. Male nematode. 26. Female nematode. 27. Internal (ventral) surface of body coil showing central ala (a). 28. Mouth opening, amphids and submedian papillae. Scale bars = 1.0 mm, 25, 26, 0.1 mm, 27, 0.01 mm, 28.

Maplestone, 1926 (see Beveridge 1982). *Spirostrongylus* possesses a lobed labial collar, while in *Cyclostrongylus*, a labial collar is totally lacking (Beveridge 1982). The specimens described here therefore belong to *Cyclostrongylus* and have previously been allocated to *C. wallabiae* (Johnston & Mawson, 1939) (see Spratt *et al.* 1991), a species which occurs commonly in the swamp wallaby, *Wallabia bicolor* (Desmarest, 1804).

The genus *Cyclostrongylus* currently comprises six species (Beveridge 1982). Morphologically, the species of *Cyclostrongylus* occurring in the oesophagus *M. irma* is most similar to *C. wallabiae* in possessing a buccal capsule which is wider in diameter towards the anterior end, rather than being perfectly cylindrical and in having regular transverse striations extending to the anterior extremity of the

buccal capsule. It was presumably for this reason that specimens of *Cyclostrongylus* from *M. irma* have hitherto been identified as *C. wallabiae* (see Spratt *et al.* 1991). However, the specimens described from *M. irma* differ in the length of spicules in the males (0.94 – 1.10 mm in *C. wallabiae*; 1.25 – 1.48 mm in specimens from *M. irma*). In addition, the bursa of *C. wallabiae* is greatly elongated dorsoventrally (Beveridge 1982, Fig. 324), while in the specimens from *M. irma*, the bursa is wider than long (Fig. 21). As a consequence of the difference in shape of the bursa, the stem of the dorsal ray is relatively much longer in *C. wallabiae* (see Beveridge 1982, Fig. 324) than in material from *M. irma*. The length of the oesophagus in specimens from *M. irma* is also shorter than those of *C. wallabiae* (0.65 – 0.75 mm in males and 0.73

0.84 mm. in females from *M. irma*, mean lengths 9.6 and 10.8 mm respectively; 0.85 – 0.97 mm in males and 0.87 – 1.02 mm in females of *C. wallabiae*, mean lengths 10.8 and 11.6 mm respectively).

The data presented here indicate that the specimens in *M. irma* are very similar but morphologically distinct from *C. wallabiae* and are therefore considered to represent a new species, herein named *C. irma* sp. nov.

The presence of the ventral ala in *C. irma* may assist the nematode in attaching to the papillae on the surface of the oesophagus of its host as has been suggested for other species (Beveridge 1982).

Beveridge & Chilton (2001) examined the relationships between species of the genus *Cyclostrongylus* and the phylogeny of their hosts. Major problems encountered in their analysis were lack of resolution both in host and parasite phylogenies. However, comparisons of the phylogenies of hosts and parasites were generally consistent with an hypothesis of co-speciation in part because all the host species are macropodids with an oesophagus lined with prominent papillae (Obendorf 1984). *Macropus dorsalis* (Gray, 1837) parasitised by *C. leptos* (Mawson, 1965), *M. eugenii* (Desmarest, 1817) parasitised by *C. kartana* (Mawson, 1955), *M. parma* Waterhouse, 1845 parasitised by *C. parma* (Johnston and Mawson, 1939), *M. parryi* Bennett, 1835 parasitised by *C. elegans* Beveridge, 1982 and *M. rufogriseus* (Desmarest, 1817) parasitised by *C. alatus* Beveridge, 1982 and *C. perplexus* Beveridge, 1982

belong to a single subgenus, *Notamacropus*, while *C. wallabiae* occurs in the related genus *Wallabia*. Two potential examples of colonization rather than host speciation were noted (Beveridge & Chilton 2001), one of which was the purported occurrence of *C. wallabiae* in both *W. bicolor* and *M. irma*. The description of the new species in *M. irma* thus potentially excludes one of these examples of colonisation and further supports the hypothesis of co-speciation between hosts and parasites in the genus.

Beveridge & Chilton (2001) argued that the cloacinine nematodes of macropodid marsupials may represent excellent models for the study of the way in which mechanisms such as co-speciation and colonization interplay in the evolution of parasitic nematodes, with their study suggesting that colonization is the more significant mechanism. However, critical for such studies is a sound taxonomic basis. The description of the two nematodes presented in this paper provides support on the one hand for the colonization hypothesis advanced for species of the *R. australis* complex and on the other hand for the co-speciation hypothesis advanced in the case of the genus *Cyclostrongylus* (see Beveridge & Chilton 2001).

Acknowledgements

We wish to express our sincere thanks Rob Brazelle for making specimens available and to Joan Clark for assistance with scanning electron microscopy.

References

- BEVERIDGE, I. (1982) A taxonomic revision of the Pharyngostromylinea Popova (Nematoda: Strongyloidea) from macropod marsupials. *Aust. J. Zool. Suppl. Ser. No.* **83**, 1-150.
- & CHILTON, N. B. (1999) Revision of the *Rugopharynx australis* (Moennig, 1926) complex (Nematoda: Strongyloidea) from macropodid marsupials. *Invert. Taxon.* **13**, 805-843.
- & — (2001) Co-evolutionary relationships between the nematode subfamily Cloacininae and its macropodid marsupial hosts. *Int. J. Parasitol.* **31**, 976-996.
- & PRESIDENTE, P. J. A. (1978) *Rugopharynx rosemariae* new species (Nematoda: Pharyngostromyloidea) from grey kangaroos (*Macropus giganteus* and *M. fuliginosus*) with life cycle stages and associated pathology. *Ibid.* **8**, 379-387.
- & SPRATT, D. M. (1996) The helminth fauna of Australasian marsupials: origins and evolutionary biology. *Adv. Parasitol.* **37**, 135-254.
- FLANNERY, T. F. (1989) Phylogeny of the Macropodoidea: a study in convergence. In G. Grigg, P. Jarman, I. Hume (Eds) "Kangaroos, Wallabies and Rat-kangaroos" (Surrey Beatty & Sons: Chipping Norton) pp. 1-46.
- OBENDORF, D. L. (1984) The macropodid oesophagus I. Gross anatomical, light microscopic, scanning and transmission electron microscopic observation of its mucosa. *Aust. J. Zool.* **32**, 415-435.
- SPRATT, D. M., BEVERIDGE, I., & WALTER, E. L. (1991) A catalogue of Australasian marsupials and monotremes and their recorded helminth parasites. *Rec. S. Aust. Mus. Monogr. Ser.* **1**, 1-105.

A CATALOGUE OF SOUTH AUSTRALIAN FRESHWATER FISHES, INCLUDING NEW RECORDS, RANGE EXTENSIONS AND TRANSLOCATIONS

By M. P. HAMMER† & K. F. WALKER**

Summary

Hammer, M. P. & Walker, K. F. (2004) A catalogue of South Australian freshwater fishes, including new records, range extensions and translocations. Trans. R. Soc. S. Aust. 128(2), 85-97, 30 November, 2004.

Published data, recent surveys and studies of museum specimens are combined to provide a list of 84 fishes for South Australia in five drainage divisions. The list includes 58 native species (44 restricted to freshwater) and 26 alien species. Seven endemics are recognised, namely *Chlamydogobius eremius* (Zeitz), *Chlamydogobius gloveri* Larson, *Craterocephalus dalhousiensis* Ivanstoff & Glover, *Craterocephalus eyresii* (Steindachner), *Craterocephalus gloveri* Crowley & Ivanstoff, *Mogurnda thermophila* Allen & Jenkins and *Neosilurus gloveri* Allen & Feinberg.

Key Words: Freshwater fishes, conservation, management, taxonomy.

A CATALOGUE OF SOUTH AUSTRALIAN FRESHWATER FISHES, INCLUDING NEW RECORDS, RANGE EXTENSIONS AND TRANSLOCATIONS

by M. P. HAMMER*[†] & K. F. WALKER*

Summary

HAMMER, M. P. & WALKER, K. F. (2004) A catalogue of South Australian freshwater fishes, including new records, range extensions and translocations. *Trans. R. Soc. S. Aust.* 128(2), 85-97, 30 November, 2004.

Published data, recent surveys and studies of museum specimens are combined to provide a list of 84 fishes for South Australia in five drainage divisions. The list includes 58 native species (44 restricted to freshwater) and 26 alien species. Seven endemics are recognised, namely *Chlamydogobius eremius* (Zeitzi), *Chlamydogobius gloveri* Larson, *Craterocephalus dalhousiensis* Ivanstoft & Glover, *Craterocephalus eyresii* (Steindachner), *Craterocephalus gloveri* Crowley & Ivanstoft, *Mogurnda thermophila* Allen & Jenkins and *Neosilurus gloveri* Allen & Feinberg. New records are reported for *Craterocephalus stercusmuscarum* ?*stercusmuscarum* (Günther), *Galaxias truttaceus* Valenciennes and *Neochanna cleaveri* (Scott), and a terapontid of uncertain status also is noted. Range extensions are reported for *Nannoperca obscura* (Klunzinger), *Nannoperca australis* Günther and an undescribed species of *Hypseleotris*, and the presence of *Galaxias olidus* Günther and *Galaxias brevipinnis* Günther in particular regions is confirmed. Possible extirpations are reported for *Ambassis agassizii* Steindachner, *Gadopsis marmoratus* Richardson, *Galaxias rostratus* Klunzinger, *Maccullochella macquariensis* (Cuvier), *Macquaria australasica* Cuvier, *Mogurnda adspersa* (Castelnau), *Neochanna cleaveri* and *Prototroctes maraena* Günther. There is need for further evaluations of fish distributions, better systematic frameworks, clarifications of conservation status, reviews of the introduction and impacts of alien species and development of protective measures for fish species and communities and their ecosystems.

KEY WORDS: Freshwater fishes, conservation, management, taxonomy

Introduction

Despite a generally dry landscape, South Australia harbours a diverse array of aquatic habitats including artesian mound springs, swamps, lakes, episodic streams and the River Murray and associated wetlands. These habitats, and the effects of biogeographical isolation (e.g. Unmack 2001), sustain a corresponding diversity of freshwater biota. The term "fresh water" here includes inland saline waters (≥ 3000 mg L⁻¹), as these are common in the state (e.g. Williams 1967; EPA 1998; Hammer 2002a).

Freshwater fishes in South Australia display a variety of physical forms and life histories. The dwarf galaxias *Galaxiella pusilla* is remarkable for its ability to survive dry periods in seasonal swamps, where it takes refuge in swamp-crayfish burrows (*Georchax*: Beck 1985). Large species like the Murray-Darling golden perch *Macquaria ambigua ambigua* may cover long distances (for example, a tagged fish is known to have travelled 2300 km along the Murray and Darling rivers: Reynolds

1983), whereas small species like the southern pygmy perch *Nannoperca australis* are much less vagile (Hammer¹). Other species need to move between fresh water and marine habitats, although even diadromous species like the galaxiids *Galaxias maculatus* and *G. brevipinnis* may occur in 'landlocked' populations (Pierce *et al.* 1985; Hammer 2002a; SKM 2002). In addition, there are euryhaline species like the small-mouthed hardyhead *Atherinosoma microstoma*, found in fresh or salt water (Molsher *et al.* 1994; Hammer 2002a).

This catalogue lists 84 species in the freshwater fish fauna of South Australia. It updates earlier work (Waite 1923; Scott *et al.* 1974; Sim 2000), corrects and amends records of species and their distributions, and is designed to assist in research and planning for management and conservation.

Methods

Drainage divisions

Five of the 13 principal drainage divisions in Australia (AWRC 1976) occur wholly or partly in South Australia, and provide a biogeographic framework (Fig. 1):

- South East Coast (SEC), including the Millicent Coast and Glenelg River (part) river basins,
- Murray Darling (MD), part of the Lower Murray River Basin,
- South Australian Gulf (SAG), the only division contained wholly within the state (the shared

* Cooperative Research Centre for Freshwater Ecology, School of Earth and Environmental Sciences DP312, The University of Adelaide, Adelaide, SA 5005. Email: michael.hammer@adelaide.edu.au

[†] Evolutionary Biology Unit, South Australian Museum.

HAMMER, M. (2001) Molecular systematics and conservation biology of the southern pygmy perch *Nannoperca australis* (Günther, 1861) (Teleostei: Percichthyidae) in south-eastern Australia. Unpub. BSc(Hons) Thesis, Department of Environmental Biology, The University of Adelaide.

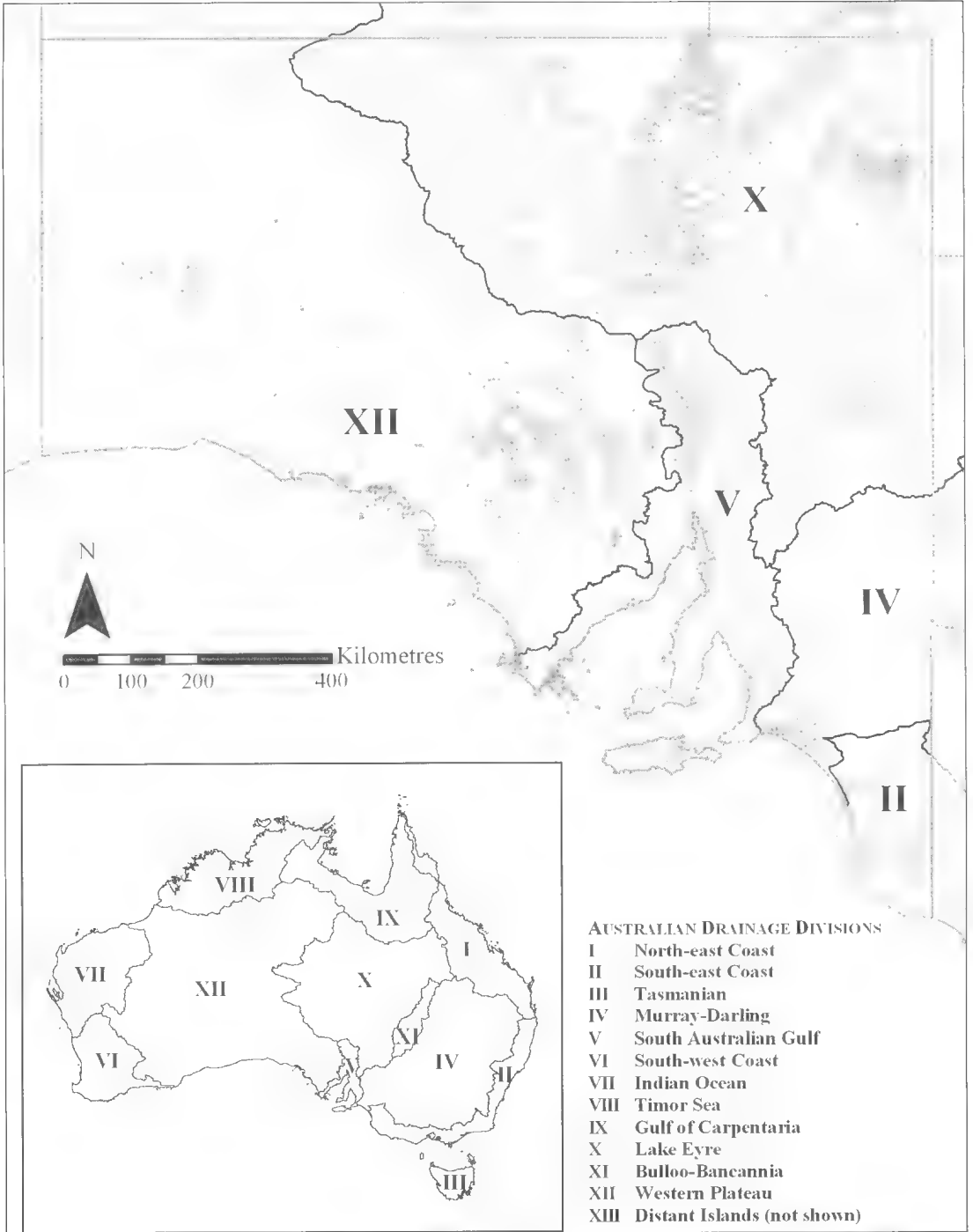


Fig. 1. Drainage divisions in Australia and South Australia (AWRC 1976).

boundary with MD is west of the Murray Mouth, but SAG includes the coastal streams of Fleurieu Peninsula),

- Lake Eyre (LE), draining toward lakes Eyre and Frome, and
- Western Plateau (WP), containing sparse coastal lakes and some ephemeral waters.

Records of species were obtained from the literature and examination of specimens at the South Australian Museum, Adelaide (SAMA), including material from recent collections by the senior author. Information on rare or doubtful species was scrutinised with special care.

Nomenclature

The systematic framework and nomenclature employed here follow Eschmeyer (1998) and subsequent updates (see Californian Academy of Sciences on-line "Catalogue of Fishes", March 2003²), except that the lamprey families Geotriidae and Mordaciidae replace Petromyzontidae (Strahan 1980), subspecific status is recognised for *M. a. ambigua* (after Musyl & Keenan 1992) and six informal taxa and a species complex are recognised. The informal taxa include dwarf flathead gudgeon *Philypnodon* sp. (Larson & Hoese 1996), Lake Eyre golden perch *Macquaria* sp. (Musyl & Keenan 1992) and western chanda perch, an undescribed species referred to in earlier literature as "*Ambassis muelleri* Klunzinger" (syn. *A. agassizii*), but lacking a formal name since "*A. muelleri*" was invalidated by Allen *et al.* (2002). The carp gudgeon genus *Hypseleotris* awaits a formal review but, following Allen *et al.* (2002), this catalogue recognizes Midgley's carp gudgeon *H. "sp. 1" sensu Hoese et al.* (1980) and Murray-Darling carp gudgeon *H. "sp. 3" sensu Unmack (2000)*. In addition, a species complex of hybrids and possible semi-clonal hybridogenic forms are recognised (Bertozzi *et al.* 2000), including Lake's carp gudgeon *H. "sp. 2" sensu Hoese et al.* (1980). Following Allen and Jenkins (1999), prior records of northern purple-spotted gudgeon *Mogurnda mogurnda* (Richardson) in South Australia should be referred to Dalhousie purple-spotted gudgeon *M. thermophila* or Flinders Ranges purple-spotted gudgeon *M. clivicola* (these were described from within the range of *M. mogurnda*).

Criteria for inclusion

A "freshwater" species here includes obligate freshwater and diadromous species and select euryhaline taxa known to complete their lifecycle in fresh water. "Alien" species include exotic species (not native to Australia) and native Australian

species translocated outside their natural range. Alien fishes in natural waterways are regarded as *established* species if their populations are self-sustaining or if they are continually stocked, and as *introduced* species if records are few and isolated or confined to artificial waterbodies (and potentially could become established). The latter include interstate translocations within drainage divisions.

Results

Native fish richness

A total of 58 native freshwater fish species in 15 families is recorded for South Australia (Table 1). All are shared with other states, except for seven endemics in isolated areas of LE. *Mogurnda clivicola* may be another endemic, as only small populations of uncertain affinity occur outside the state (Allen & Jenkins 1999; Wager & Unmack 2000).

Forty-four native species are confined to fresh water. One of these, Australian smelt *Retropinna semoni*, may occasionally occur in the Coorong (Eckert & Robinson 1990), but is not strictly diadromous. Four euryhaline taxa meet the aforementioned criteria of "freshwater" species, namely *A. microstoma*, flathead gudgeon *Philypnodon grandiceps*, western bluespot goby *Pseudogobius olorum* and lagoon goby *Tasmanogobius lasti* (e.g. Wedderburn & Hammer 2003). Thirteen of the 44 obligate freshwater species occur in more than one division, and none is common to all. Most obligate freshwater species occur in LE (24) and MD (24), plus 11 diadromous and euryhaline taxa. Diadromous and euryhaline species generally occur in more than one division. Remarkably, three diadromous species are recorded for WP, although data there are sparse (Table 1).

New records for South Australia

Fly-specked hardyhead *Craterocephalus stercusmuscarum* *?stercusmuscarum* (Günther)

This taxon was identified in samples collected from the northern Flinders Ranges in 1994-95 (SAMA F7331, F9002, F9078). It is distinguished from the Lake Eyre hardyhead *Craterocephalus eyresii* (Steindachner), which occurs in the same region but not the same habitats, by fewer transverse scale rows (7-8 cf. 11-14 in *C. eyresii*) and dark lateral banding (Ivanstovff *et al.* 1987; Crowley & Ivanstovff 1990a). Subspecific identification is tentative owing to taxonomic problems and the isolated nature of the population (the nearest known conspecifics are from Aramac Springs in the remote

² <http://www.calacademy.org/research/ichthyology/catalog/fishcatmain.asp>

TABLE 1. Native freshwater fishes in drainage divisions of South Australia. [X – recorded; E – presumed extinct; ? – uncertain status]. *Endemic to South Australia. †See text.

Family	Taxon	Common name	Division				
			SEC	MD	SAG	LE	WP
Geotriidae	<i>Geotria australis</i> Grey, 1851	Pouched lamprey	X	X	X		
	<i>Mordax mordax</i> (Richardson, 1846)	Shortheaded lamprey	X	X	X		
	<i>Anguilla australis</i> Richardson, 1841	Shortheaded eel	X	X	X		
	<i>Neosiluroides cooperensis</i> Allen & Feinberg, 1998	Cooper catfish				X	
	<i>Neosilurus gloveri</i> Allen & Feinberg, 1998#	Dalhousie catfish				X	
Anguillidae	<i>Neosilurus hyrllii</i> Steindachner, 1867	Hyrll's catfish				X	
	<i>Porochilus argenteus</i> (Zietz, 1896)	Silver tandan				X	
	<i>Tandanus tandanus</i> Mitchell, 1838	Freshwater catfish		X			
	<i>Nematolosa erebi</i> (Günther, 1868)	Bony herring		X	?	X	
	<i>Prototroctes maraena</i> Günther 1864	Australian grayling	E				
Clupeidae	<i>Retropinna semoni</i> (Weber, 1895)	Australian smelt		X		X	
	<i>Galaxias brevipinnis</i> Günther, 1866	Climbing galaxias		X	X		
	<i>Galaxias maculatus</i> (Jenyns, 1842)	Common galaxias	X		X		
	<i>Galaxias olidus</i> Günther, 1866	Mountain galaxias	X	X	X		
	<i>Galaxias rostratus</i> Klunzinger, 1872	Murray galaxias		E			
Retropinnidae	<i>Galaxias truttaceus</i> Valenciennes, 1846	Spotted galaxias	X				
	<i>Galaxiella pusilla</i> (Mack, 1936)	Dwarf galaxias	X				
	<i>Neochanna cleaveri</i> (Scott, 1934)	Tasmanian mudfish	X				
	<i>Melanotaenia fluviatilis</i> (Castelnau, 1878)	Murray rainbowfish	?	X		X	
	<i>Melanotaenia splendida tatei</i> (Zietz, 1896)	Desert rainbowfish					
Atherinidae	<i>Atherinosoma microstoma</i> (Günther, 1861)	Small-mouthed hardyhead	X	X	X	X	X
	<i>Craterocephalus dalhousiensis</i> Ivanstöff & Glover, 1974#	Dalhousie hardyhead					
	<i>Craterocephalus eyresii</i> (Steindachner, 1883)#	Lake Eyre hardyhead			X	X	?
	<i>Craterocephalus fluviatilis</i> McCulloch, 1912	Murray hardyhead		X			
	<i>Craterocephalus gloveri</i> Crowley & Ivanstöff, 1990#	Glover's hardyhead		X		X	
Ambassidae	<i>Craterocephalus stercusmuscarum</i> Ivanstöff, Crowley & Allen, 1987	Unspecked hardyhead		X		X	
	<i>Craterocephalus stercusmuscarum</i> ? <i>stercusmuscarum</i> (Günther, 1867)	Fly-specked hardyhead		E			
	<i>Ambassis agassizii</i> Steindachner, 1867	Chanda perch					
	<i>Ambassis</i> sp. (undescribed)†	Western chanda perch	X	X	E	X	
	<i>Gadopsis marmoratus</i> Richardson, 1848	Trout cod		E			
Percichthyidae	<i>Maccullochella macquariensis</i> (Cuvier, 1829)	Murray cod		X			
	<i>Maccullochella peelii peelii</i> (Mitchell, 1838)	Murray-Darling golden perch		X			
	<i>Macquaria ambigua ambigua</i> (Richardson, 1845)	Macquarie perch		E			
	<i>Macquaria australasica</i> Cuvier, 1830	Estuary perch	X	X			
	<i>Macquaria colonorum</i> (Günther, 1863)	Lake Eyre golden perch				X	
Namoperca	<i>Namoperca</i> sp. (undescribed)†	Southern pygmy perch	X	X	X		
	<i>Namoperca australis</i> Günther, 1861	Yarra pygmy perch	X	X			
	<i>Namoperca obscura</i> (Klunzinger, 1872)						

Family	Taxon	Common name	SEC	MD	Division	LE	WP
Terapontidae	<i>Nannoperca variegata</i> Kuitert & Allen, 1986	Variegated pygmy perch	X				
	<i>Amitatiba percoides</i> (Günther, 1864)	Banded grunter				X	
	<i>Bitychanus bitychanus</i> (Mitchell, 1838)	Silver perch		X			
	<i>Bitychanus welchi</i> (McCulloch & Waite, 1917)	Welch's grunter				X	
	<i>Leiopotherapon unicolor</i> (Günther, 1859)	Spangled grunter		X	?	X	
	<i>Scortum barcoo</i> (McCulloch & Waite, 1917)	Barcoo grunter				X	
	<i>Pseudaphritis urvillii</i> (Valenciennes, 1832)	Congolli	X	X	X		X
	<i>Hypseleotris klunzingeri</i> (Ogilby, 1898)	Western carp gudgeon		X		X	
	<i>Hypseleotris</i> sp. 1 (undescribed) [†]	Midgley's carp gudgeon		X		X	
	<i>Hypseleotris</i> sp. 3 (undescribed) [†]	Murray Darling carp gudgeon		X	X		
Pseudaphritidae	<i>Hypseleotris</i> spp. (species complex) [‡]	Hybrid forms (e.g. Lake's carp gudgeon)	X			X	
	<i>Mogurnda adspersa</i> (Castelnau, 1878)	Southern purple-spotted gudgeon		E	E		
	<i>Mogurnda clivicola</i> Allen & Jenkins, 1999	Flinders Ranges purple-spotted gudgeon				X	
	<i>Mogurnda thermophila</i> Allen & Jenkins, 1999 [‡]	Dalhousie purple-spotted gudgeon				X	
	<i>Philypnodon grandiceps</i> (Kreffl, 1864)	Flathead gudgeon	X	X	X		
	<i>Philypnodon</i> sp. (undescribed) [†]	Dwarf flathead gudgeon		X	?		
	<i>Chlamydogobius eremius</i> (Zeitz, 1896) [#]	Desert goby				X	
	<i>Chlamydogobius gloveri</i> Larson 1995 [#]	Dalhousie goby				X	
	<i>Pseudogobius olorum</i> (Sauvage, 1880)	Western bluespot goby	X	X	X		X
	<i>Tasmanogobius lasti</i> Hoese, 1991	Lagoon goby	X	X	X		
Gobiidae							
Totals (Grand Total 58)			19	35	16	24	3

upper reaches of Cooper Creek, Queensland). A molecular revision of *Craterocephalus* in progress indicates that sub-species within the *C. stercusmuscarum* species complex remain confused (P. Unmack, Arizona State University, pers. comm.) and further morphological and molecular analyses are required.

Spotted galaxias *Galaxias truttaceus* Valenciennes

This species was first reported in 1999 from karstic springs in coastal south-eastern South Australia (e.g. Ewens Ponds: Hammer *et al.* 2000; SAMA F9217, F10111) representing a minor westward range extension into South Australia. Another single specimen from the same area occurred among specimens of *G. maculatus* collected in 1979 (SAMA F10109). Note that a prior report of *G. truttaceus* from SAG (Scott *et al.* 1974) was based on misidentified specimens (SAMA F3094, F3188).

Tasmanian mudfish *Neochanna cleaveri* (Scott)

This species is known in South Australia only from a single specimen collected from Bool Lagoon in 1974, and previously registered as *G. maculatus* (SAMA F4919). Recent surveys have failed to locate others (Hammer 2002a). The new record is noteworthy as the species is cryptic, with an ability to survive extended dry periods by burrowing into mud or hiding under rocks and wood, and otherwise is native to Tasmania and Victoria (Fulton 1986; Koehn & Raadik 1991).

A possible new terapontid

A form of grunter (Terapontidae) resembling a deep-bodied Welch's grunter *Bidyanus welchi* or a hybrid *B. welchi* x Barcoo grunter *Scortum barcoo* is known from Coongie Lakes (J. Puckridge, University of Adelaide, pers. comm. 2001). This form is listed as the 'Cooper grunter' by Sim (2000). It was also reported near Goyder Lagoon on the lower Warburton River in 2002 (Costelloe *et al.* 2003).

Range extensions

Surveys in the Mount Lofty Ranges (Hammer¹) have provided three new drainage division records, namely a genetically distinct sub-population of *Nannoperca australis* from the Inman River Catchment (SAG), *Hypseleotris* sp. 3 from the same location, and Yarra pygmy perch *Nannoperca obscura* from Lake Alexandrina (MD). The review uncovered other, previously misidentified specimens

of *N. obscura* in the museum collection dating from 1915 (SAMA F572), suggesting the species is native.

The presence of mountain galaxias *Galaxias olidus* (a species complex presently under systematic review: Raadik 2001) recently was confirmed from the South Australian section of SEC (Mosquito Creek: Hammer 2002a). Despite its inclusion in a south east regional list by Glover (1983), no specimens of the species were previously known. In addition, Glover mistakenly referred to the Mosquito Creek population as *G. maculatus*. The presence of *G. brevipinnis* in MD is also confirmed (SAMA F153: Angas River, 1914; previously registered as *G. maculatus*), a record predating the Snowy Mountains Hydroelectric Scheme which appears to be the source of *G. brevipinnis* in the upper Murray catchment (Waters *et al.* 2002).

A report of *R. semoni* from SAG (SKM 2002) is suspect because voucher specimens are not available and no other records exist for the division (e.g. McDowall 1979; Unmack 2001). Other SAG reports of bony herring *Nematalosa erebi* and spangled grunter *Leiopotherapon unicolor* in the Lake Torrens catchment, and western carp gudgeon *Hypseleotris klunzingeri* as native to the Broughton River (Pierce *et al.* 2001) are also discounted in the absence of voucher specimens or other data. There is an uncertain report of fish resembling *C. eyresii* in the remote, isolated Durkin Swamp (WP), following exceptional rainfall (Ehmann & Tynan 1997).

Finke goby *Chlamydogobius japalpa* Larson, Finke hardyhead *Craterocephalus centralis* Crowley & Ivanstoft and Finke purple-spotted gudgeon *Mogurnda larapintae* (Zeitz) potentially could colonise the ephemeral, lower reaches of the Finke River in South Australia, following floods from the headwaters in the Northern Territory, but they have not been formally recorded.

Alien species

There are records of 26 alien species in South Australia (Tables 2-3), although two may prove to be natives (*Philypnodon* sp. from the Onkaparinga River (SAG) (SAMA F10087, April 2002), and Murray rainbowfish *Melanotaenia fluviatilis* from SEC (SAMA F2409, dated 1903)). Most alien species records are for SAG (20 species, including 13 established alien species). There are high numbers also for MD and SEC, but few in the remote LE and WP (Table 2).

Fourteen alien species are established in South Australia. These include seven exotic taxa and seven translocated native taxa. Another 12 alien species have been introduced, but are not established or present only in artificial waterways (Tables 2-3). These include barramundi *Lates calcarifer* in the River Torrens and Australian bass *Macquaria*

TABLE 2. *Alien fishes in fresh water environments in drainage divisions of South Australia.* [X = continually introduced and or established; I = introduced, few records; A = introduced to artificial habitats (e.g. farm dams, sewage treatment ponds); ? = uncertain status]. *See text.

Family	Taxon	Common name	SEC	MD	Division		
					SAG	LE	WP
EXOTIC SPECIES							
Cyprinidae	<i>Carassius auratus</i> (Linnaeus, 1758)	Goldfish	X	X	X	X	A
	<i>Cyprinus carpio</i> Linnaeus, 1758	Common carp	I	X	X	X	A
	<i>Tinca tinca</i> (Linnaeus, 1758)	Tench	X	X	X	X	
	<i>Misgurnus anguillicaudatus</i> (Cantor, 1842)	Oriental weatherloach		I			
	<i>Oncorhynchus mykiss</i> (Walbaum, 1792)	Rainbow trout	I	X	X		
Salmonidae	<i>Salmo salar</i> Linnaeus, 1758	Atlantic salmon		I			
	<i>Salmo trutta</i> Linnaeus, 1758	Brown trout	I	X	X		
	<i>Salvelinus fontinalis</i> (Mitchell, 1814)	Brook trout			I		
Poeciliidae	<i>Gambusia holbrooki</i> Girard, 1859	Gambusia	X	X	X	X	I
Percidae	<i>Percia fluviatilis</i> Linnaeus, 1758	European perch	X	X	X	I	
TRANSLOCATED AUSTRALIAN NATIVE SPECIES							
Plotosidae	<i>Tandanus tandanus</i> (Mitchell, 1838)	Freshwater catfish	I	A	X		
	<i>Galaxiella pusilla</i> (Mack, 1936)	Dwarf galaxias			I?		
	<i>Melanotaenia fluviatilis</i> (Castelnau, 1878)	Murray rainbowfish	I?		X		
Centropomidae	<i>Lates calcarifer</i> (Bloch, 1790)	Barramundi			I		
	<i>Ambassis agassizii</i> Steindachner, 1867	Chanda perch		A			
	<i>Gadopsis marmoratus</i> Richardson, 1848	River blackfish			A		
Percichthyidae	<i>Maccullochella peelii peellii</i> (Mitchell, 1838)	Murray cod	I	A	X	I	
	<i>Macquaria ambigua ambigua</i> (Richardson, 1845)	Murray-Darling golden perch	I	A	X	A	
	<i>Macquaria novemaculeata</i> (Steindachner, 1866)	Australian bass	I	A	X		
	<i>Nannoperca australis</i> Günther, 1861	Southern pygmy perch		I			
	<i>Bidyanus bidyanus</i> (Mitchell, 1838)	Silver perch	I	A	A	A	
Terapontidae	<i>Hypseleotris</i> sp. 1 (undescribed) [†]	Midgley's carp gudgeon					
	<i>Hypseleotris</i> sp. 3 (undescribed) [†]	Murray Darling carp gudgeon	X				
	<i>Mogurnda adspersa</i> (Castelnau, 1878)	Southern purple-spotted gudgeon		A	A		
	<i>Oxyeleotris lineolata</i> (Steindachner, 1867)	Sleepy cod		I			
	<i>Philypnodon</i> sp. (undescribed) [†]	Dwarf flathead gudgeon			X?		
Totals (Grand Total 26)			13	17	20	7	2
Total established (Grand Total 14)			5	7	13	2	0

TABLE 3. *Distributions annotations for selected freshwater fishes in South Australia (in support of Tables 1-2). [Record types: 1 range extension or new state record; 2 restricted presence; 3 established alien species; 4 introduced; 5 - erroneous report], SA - South Australia; Vic. Victoria; SAMA - South Australian Museum, Adelaide; AM - Australian Museum, Sydney; SMNS = Staatliches Museum für Naturkunde, Stuttgart, Germany*

Species	Record	Details	Type	Source
SOUTH EAST COAST DRAINAGE DIVISION				
<i>Galaxias truttaceus</i>	1	Lower south east SA, springs and coastal creeks.		Hammer (2002a) = SAMA F9217; F10109 (1979)
<i>Neochanna cleaveri</i>	1	Specimen from Bool Lagoon labelled as <i>Galaxias maculatus</i> .		SAMA F4919 (1974)
<i>Galaxias olidus</i>	2	Mosquito Creek. Referred to as <i>Galaxias maculatus</i> by Glover (1983).		Hammer (2002a) = SAMA F10121
<i>Geotria australis</i>	2	Photographed in Ewens Ponds. Collected from Glenelg R. in SA.		Kuiter (1983); SAMA F1046 (1928)
<i>Macquaria colonorum</i>	2	Glenelg R. in SA.		SAMA F1704 (1932); Hammer (2002a)
<i>Mordacia mordax</i>	2	Near Port MacDonnell. Other SAMA records from western Vic.		F10103 (1982)
<i>Prototroctes marcuia</i>	2	Photographed in Ewens Ponds. No recent records.		Kuiter (1983); Hammer (2002a)
<i>Tasmanogobius lasii</i>	2	Some freshwater lakes (e.g. L. Bonney).		Hammer (2002a)
<i>Hypseleotris</i> sp. 3	3	No records <1980; now widespread in Millicent Coast Basin.		Hammer (2002a); SAMA F10144
<i>Tinca tinca</i>	3	Naracoorte Creek, L. Cockatoo.		SAMA F7700 (1995); Hammer (2002a)
<i>Cyprinus carpio</i>	4	One record from Bool Lagoon (1995), unconfirmed report for Valley L.		Glover (1983); Hammer (2002)
<i>Oncorhynchus mykiss</i> and <i>Salmo trutta</i>	4	Mosquito Creek, Ewens Ponds. Previously stocked and/or farm escapees. No recent reports.		SAMA F1918 (1936); Atkins <i>et al.</i> (1988); Hammer (2002a)
<i>Tandanus tandanus</i>	4	Lucindale (1936). Stocked with <i>Bidymanus bidyanus</i> , <i>Maccullochella peelii pealii</i> , <i>Macquaria ambigua ambigua</i> .		SAMA F2409 (1903). Concurrent collections - SAMA F1901, 1368
<i>Maculotaenia fluviatilis</i>	4	Freshwater L. near Kingston and Robe with <i>Atherinosoma microstoma</i> and <i>Gadopsis marmoratus</i> . Could be native.		AM IB7303, 7304 cf. Glover (1983)
<i>Craterocephalus stercoriscarum</i>	5	Mis-identified <i>Atherinosoma microstoma</i> .		Hammer (2002) cf. Atkins <i>et al.</i> (1988)
<i>Hypseleotris klunzingeri</i>	5	Probably <i>Hypseleotris</i> sp. 3, as above.		Hammer (2002a) cf. Larson & Hoese (1996)
<i>Philypnodon</i> sp.	5	Absent in region.		Hammer (2002a)
<i>Retropinna semoni</i>	5	Absent between Glenelg R. and the Murray.		
MURRAY DARLING DRAINAGE DIVISION				
<i>Vannopoma obscura</i>	1	L. Alexandrina (2001). SAMA specimens date from 1915.		Hammer ¹ = SAMA F10008 (2001); SAMA F572 (1915)
<i>Anguillic australis</i>	2	Occasional R. Murray records, also streams near L. Alexandrina.		e.g. SAMA F3712 (1972), F7798 (1996)
		At western-most range for larval migration (inc. K.I. also, see SAG).		
<i>Galaxias brevipinnis</i>	2	Large adult from Angas R.		SAMA F153 (1914)
<i>Galaxias rostratus</i>	2	Syntypes (R. Murray SA) SMNS, some redeposited with AMS.		SMNS 1597 (1868), ?1696 (1869); AM I19743;
		Another specimen from Murray Bridge needs verification.		McDowall and Frankenberg (1981)
<i>Leiopotherapon unicolor</i>	2	Coorong and L. Alexandrina in 1976 after floods.		SAMA F4152, F4247
<i>Macquaria australasica</i>	2	Upper SA section of R. Murray (historically rare).		Zeitz (1902); SAMA F456 (1917), F497 (1918)
<i>Macquaria colonorum</i>	2	Lower Murray, L. Albert, Alexandrina and Coorong.		Eckert & Robinson (1990); Sim <i>et al.</i> (2000)
<i>Maccullochella macquariensis</i>	2	Early record from Purnong on R. Murray. Range extension from upstream populations (e.g. Mildura in 1940-50s).		SAMA 1672 (1932); Cadwallader (1977)
<i>Tasmanogobius lasii</i>	2	L. Albert and Alexandrina (freshwater), apparently spawns in these regions.		Sim <i>et al.</i> (2000); Wedderburn & Hammer (2003)

Species	Record Type	Details	Source
<i>Tinca tinca</i>	3	Once common. Occasionally recorded (e.g. Angas R.).	SAMA F10102 (1999); Sim <i>et al.</i> (2000)
<i>Ambassis agassizii</i> and <i>Mogurnda adpersa</i>	4	Transferred from Darling R. basin in Queensland to Murray Bridge Army Range, to be later released to R. Murray.	Pierce (1997)
<i>Macquaria novemaculeata</i>	4	Near Loxton, per professional fisher.	SAMA F7169 (1992); Pierce (1992)
<i>Misgurnus anguillicaudatus</i>	4	Unconfirmed report for R. Murray at Long Island, Murray Bridge (1980s). Now spreading downstream from Vic.	Wedderburn [†] ; Koster <i>et al.</i> (2002)
<i>Oxyeleotris lineolata</i>	4	Two R. Murray records. Museum specimen from Kroehns Landing (near Nildotte). Another displayed at Swan Reach Hotel, September 2003, caught near Nildotte per professional fisher.	SAMA F10143 (1995)
<i>Salmo salar</i>	4	Three R. Murray specimens caught near Renmark by professional fishers.	SAMA F7284, F7504, F7505 (1993)
SOUTH AUSTRALIAN GULF DIVISION			
<i>Hypseleotris</i> sp. 3	1	Inman R. catchment. Presumed native as sympatric with <i>Nannoperca australis</i> .	Hammer [†]
<i>Nannoperca australis</i>	1	Inman R. catchment, a genetically distinct population of Murray lineage.	Hammer [†]
<i>Anquilla australis</i>	2	South coast catchments of Kangaroo Island.	SAMA F4718, F5175 (1980's)
<i>Craterocephalus cyresii</i>	2	L. Torrens catchment; L. Torrens when full, springs, Willochra Creek.	e.g. SAMA F3176 (1961), F9153 (1996)
<i>Gadopsis marmoratus</i>	2	Historically an edible fish of the Onkaparinga and Torrens rivers. Presence on Kangaroo Island (location unknown) needs verification.	Zietz (1902); SAMA F6467 (1987)
<i>Mogurnda adpersa</i>	2	Historic records for Torrens, Onkaparinga rivers. No reports for >50 years.	SAMA F517, F518 (pre 1917)
<i>Tasmanogobius lasti</i>	2	Lower reaches of Kangaroo Island streams.	Hoesle (1991); Hammer pers. obs. 2003
<i>Macquaria ambigua ambigua</i>	3	Introductions do occur (e.g. Clarendon Weir, Broughton R.).	SKM 2002; Bochow (2003)
<i>Maccullochella peelii peellii</i>	3	Regularly stocked into Broughton R.	e.g. Bochow (2003)
<i>Melanotaenia fluviatilis</i> and <i>Hypseleotris</i> sp. 1	3	R. Torrens, common in lower reaches.	e.g. SAMA F9277 (1999), F9279 (1999); Hammer pers. obs. 2000-2003.
<i>Philypodon</i> sp. nov.	3	First record from Onkaparinga R., 2002. Could be native.	SAMA F10087 (2002)
<i>Tandanus tandanus</i>	3	Torrens, Wakefield rivers.	SAMA F9086 (1997); Hicks & Sheldon (1998)
<i>Tinca tinca</i>	3	Few catchments (e.g. Onkaparinga).	SKM (2002); Hammer pers. obs. 1998
<i>Gadopsis marmoratus</i> and <i>Nannoperca australis</i>	4	Refuge population in dams at Warrawong Sanctuary since 1980's (trib. Onkaparinga R.).	Hammer pers. obs. 1999-2002
<i>Galaxiella pusilla</i>	4	Listed without detail.	Carter & Pierce [‡]
<i>Lates calcarifer</i>	4	Netted from R. Torrens (Torrens L.), April 2002 (376 mm total length).	SAMA F00000 [registry number pending]
<i>Mogurnda adpersa</i>	4	Stocked into Thorndon Park Reservoir (since dried).	Anon. (1996)
<i>Salvelinus fontinalis</i>	4	Previously stocked into Sixth Creek, Torrens Catchment.	Scott <i>et al.</i> (1974)

[†] WEDDERBURN, S. (2000) Habitat and conservation status of small fish in the Lower River Murray, and a comparison of the western carp gudgeon (*Hypseleotris klunzingeri*) and gambusia (*Gambusia holbrooki*) as larval mosquito predators. Unpub. BSc (Hons) Thesis, Department of Environmental Biology, University of Adelaide, Adelaide.

[‡] CARTER, J. & PILBRI, B. (undated) Freshwater fishes of the Mount Lofty Ranges. Department for Environment and Natural Resources, Adelaide. (unpub.). 18 p.

Species	Record Details Type	Source
LAKE EYRE DRAINAGE DIVISION		
<i>Craterocephalus stercusmuscarum</i>	1	SAMA F7331, F9002, F9078 (1994/95)
<i>?stercusmuscarum</i>	2	Glover (1985); Hammer pers. obs. 2002
<i>Amniataba percoideus</i>	3	SAMA F6199 (1986); Reid & Puckridge (1990)
<i>Carassius auratus</i>	4	Pierce <i>et al.</i> (2001)
<i>Cyprinus carpio</i>	4	Pierce (1990)
<i>Maccullochella peelii peelii</i>	4	Wager & Unmack (2000)
<i>Macquaria ambigua ambigua</i> and <i>Macquaria ambigua</i>	4	Glover (1980); Pierce <i>et al.</i> 2001
<i>Bidyanus bidyanus</i>	4	SAMA F5496 (1981), F7405 (1982)
<i>Percu fluviatilis</i>	2	SAMA 2615 (1947), F4789 (1984)
WESTERN PROVINCE DRAINAGE DIVISION		SAMA F1388 (1929)
<i>Pseudogobius olorum</i>	2	SAMA F10056 (1947)
<i>Atherinosoma microstoma</i>	2	Glover (1979)
<i>Pseudaphritis urvillii</i>	2	
<i>Gambusia holbrooki</i>	3	
<i>Carassius auratus</i>	4	

novemaculeata, sleepy cod *Oxyeleotris lineolata* and Atlantic salmon *Salmo salar* in the River Murray. *Gambusia* *Gambusia holbrooki* and goldfish *Carassius auratus* were recorded in all drainage divisions.

Four large native MD species (silver perch *Bidyanus bidyanus*, Murray cod *Maccullochella peelii peelii*, freshwater catfish *Tandanus tandanus*, *M. a. ambigua*) are spawned in commercial hatcheries in other states and are commonly introduced to South Australia (Tables 2-3), including undocumented stockings in farm dams in MD and SAG.

Translocations in drainage divisions within South Australia are not considered in detail here, but have reportedly included transportation of *M. clivicola* in the Flinders Ranges region and fish from Cooper Creek to a retention dam at Leigh Creek (see Pierce *et al.* 2001).

Extirpations and species decline

Museum records are not necessarily a true indication of range and abundance, but indications from all sources combined are that there have been significant declines in the range of several species. Records for some species may represent occasional stray individuals on the fringe of their geographic range, but these could not be distinguished from established species due to a paucity of detailed historic surveys and/or temporal replication.

There is historical evidence (Table 3) that Murray galaxias *Galaxias rostratus*, trout cod *Maccullochella macquariensis* and Macquarie perch *Macquaria australasica* formerly occurred in MD in South Australia. *Ambassis agassizii* was last recorded from the Marne River mouth (MD) in 1983 (Lloyd & Walker 1986), and state-wide extirpation appears confirmed for the southern purple-spotted gudgeon *Mogurnda adspersa* (last record in MD 1973: SAMA F3727; no sightings in SAG for >50 years). The river blackfish *Gadopsis marmoratus* can be considered extirpated from SAG (it may persist on Kangaroo Island, but the record is dubious: Table 3) and has undergone significant range contraction in MD (Sim *et al.* 2000), exacerbated since 1997 by the loss to irrigation diversions of more than half of the spring-fed habitats in the Marne River, one of few remaining refuges (Hammer 2002b). Similarly, range contraction and on-going local extirpations have been recorded for *N. australis* (Hammer¹). Estuary perch *Macquaria colonorum* was once more widespread in the lower Murray prior to the construction of barrages near to the Murray Mouth (Sim *et al.* 2000). For SEC, *N. cleaveri* and the Australian grayling *Prototroctes maraena* have not been reported since 1974 and 1982 respectively and

other SEC species including *G. pusilla* have likely suffered large range reductions coinciding with massive loss of wetland habitat (Hammer 2002a).

Other species are confined to small areas, including five endemic species in Dalhousie Springs (LE) (Wager & Unmack 2000), *M. clivicola* (recorded only from Balcanoona Creek in the Flinders Ranges (LE): e.g. SAMA F3042), Murray hardyhead *Craterocephalus fluvialis* (very few sites in the lower Murray (MD): Lloyd & Walker 1986; Wedderburn & Hammer 2003); *N. obscura* (three habitat fragments in SEC and a small section of MD: Hammer 2002a; Wedderburn & Hammer 2003) and the variegated pygmy perch *Nannoperca variegata* (a 4-km² spring-fed area in SEC: Hammer *et al.* 2000).

Discussion

This catalogue is a contribution toward an inventory of state and regional biodiversity. Well-maintained historic collections and voucher specimens are critical to record information, validate doubtful records and sustain progress in taxonomy, ecology and conservation. Ideally, this information should be updated frequently, as work progresses.

Although surface waters in South Australia are limited (NLWRA 2001), the state harbours about one fifth of the continental freshwater fish fauna. As the state borders intersect, rather than enclose, some drainage divisions, and as most divisions allow access to the sea, the number of endemic species is comparatively low. Some 'new' records here arise from minor re-alignments of physiographic boundaries between drainage divisions or states (e.g. South Australian Gulf Drainage Division: *N. australis*; South East Coast Drainage Division: *G. truttaceus*), but others represent significant range extensions (e.g. Murray Darling Drainage Division: *N. obscura*; South East Coast Drainage Division: *N. cleaveri*; Lake Eyre Drainage Division: *C. s. ?stercusmuscarum*).

Biodiversity assessments and monitoring should favour obligate freshwater fishes isolated within particular drainage divisions or regions, because they are most likely to have diverged (cf. Crowley & Ivanstovff 1990a,b; Musyl & Keenan 1992; Larson 1995; Allen & Jenkins 1996; Allen & Feinberg 1998; Hammer¹). These studies may gain impetus from assessments of ecosystem 'health', as fishes are

potential indicators (e.g. Harris 1995). Clarifications are needed in regard to the taxonomy of undescribed taxa, species complexes and the biogeographic status of some species, especially where there are few historical data. Fine-scale molecular markers may help to distinguish natural and translocated populations (e.g. Waters *et al.* 2002).

Alien freshwater fishes are ubiquitous in South Australia. They are most apparent in areas directly affected by human industry, particularly in the Murray Darling and South Australian Gulf drainage divisions. All such species are potential vectors for pathogens and parasites (e.g. Langdon & Humphrey 1987). Predators like brown trout *Salmo trutta*, rainbow trout *Oncorhynchus mykiss* and European perch *Perca fluviatilis* are implicated in the decline of small native fishes (e.g. Crowl *et al.* 1992; Morgan *et al.* 2002). *Gambusia holbrooki* is an aggressive, highly fecund competitor that undoubtedly has affected native species (e.g. Lloyd³). The feeding behaviour and high abundance of common carp *Cyprinus carpio* have contributed to destruction of wetlands associated with the River Murray (e.g. Sim *et al.* 2000), and thereby affected native fishes. There is also some risk of genetic contamination of native stocks by translocated native species (Arthington 1991).

The preservation of native biota is a management priority in South Australia (e.g. Kahrimanis *et al.* 2001; EPA 2003), and avenues for the introduction of non-native fishes such as the government-sanctioned releases of salmonids, sales of fingerling angling species to the public, "conservation" stocking, releases of unwanted aquarium fishes and inter-basin transfers from the River Murray all need review within broadly-based programs of flow and habitat protection, particularly where small isolated populations of native fish occur.

Acknowledgements

We gratefully acknowledge access to the collections of the South Australian Museum, financial support to MPH from the Nature Foundation (SA) and technical help from S. Wedderburn. T. Raadik, Arthur Rylah Institute, Melbourne, kindly identified several galaxiids and assisted with information on *G. rostratus* and T. Trnski confirmed the identity of hardyheads at the Australian Museum, Sydney. Our thanks also to members of Native Fish Australia (SA) for field assistance and to A. George for advice on GIS data. Comments on a draft manuscript by two referees were greatly appreciated.

¹ LLOYD, L. N. (1987) Ecology and distribution of the small native fish of the lower River Murray, South Australia, and their interactions with the exotic mosquitofish, *Gambusia affinis holbrooki*. Unpub. MSc Thesis, Department of Zoology, The University of Adelaide.

References

- ALLEN, G. R. & FEINBERG, M. N. (1998) Descriptions of a new genus and four new species of freshwater catfishes (Plotosidae) from Australia. *Aqua - Journal of Ichthyology and Aquatic Biology* **3**, 9-18.
- & JENKINS, A. P. (1999) A review of the Australian freshwater gudgeons, genus *Mogurnda* (Eleotridae) with description of three new species. *Aqua - Journal of Ichthyology and Aquatic Biology* **3**, 141-156.
- , MIDGLEY, S. H. & ALLEN, M. (2002) "Field Guide to the Freshwater Fishes of Australia" (Western Australian Museum, Perth).
- ANON. (1996) Thorndon Park Reservoir bouncing back. *Southern Fisheries* **4**, 4.
- ARTINGTON, A. H. (1991) Ecological and genetic impacts of introduced and translocated freshwater fishes in Australia. *Canadian Journal of Fisheries and Aquatic Sciences* **48** (Supplement 1), 33-43.
- ATKINS, B. P., LLOYD, L. N. & GREY, J. D. (1988) Fishes. In: Wetlands of the Bakers Ridge and Marcollat Watercourses. Department of Environment & Planning, Adelaide. 122 p.
- AUSTRALIAN WATER RESOURCES COUNCIL (1976) Review of Australia's Water Resources 1975. Australian Water Resources Council, Canberra. 170 p.
- BECK, R. G. (1985) Field observations upon the dwarf galaxiid *Galaxiella pusilla* (Mack) (Pisces: Galaxiidae) in the south-east of South Australia, Australia. *South Australian Naturalist* **60**, 12-22.
- BERTOZZI, T., ADAMS, M. & WALKER, K. F. (2000) Species boundaries in carp gudgeons (Eleotridae: *Hypseleotris*) from the River Murray, South Australia: evidence for multiple species and extensive hybridization. *Marine and Freshwater Research* **51**, 805-815.
- BOCIOW, B. (2003) Cudgee down south. *South Australian Angler* June/July, 36-37.
- CADWALLADER, P. L. (1977) Fisheries and Wildlife paper, Victoria number 13: J. O. Langtry's 1949-50 Murray River investigations. Ministry for Conservation, Fisheries & Wildlife Division, Melbourne. 70 p.
- COSTELLOE, J. F., HUDSON, P., PRITCHARD, J. C., PUCKRIDGE, J. T. & REID, J. R. W. (2003) ARIDFLO - environmental flow requirements of arid zone rivers. Final report to Environment Australia, Canberra. 123 p.
- CROWL, T. A., TOWNSEND, C. R. & MCINTOSH, A. R. (1992) The impact of introduced brown and rainbow trout on native fish: the case of Australasia. *Reviews in Fish Biology and Fisheries* **2**, 217-241.
- CROWLEY, L. E. L. M. & IVANSTOFF, W. (1990a) A review of species previously identified as *Craterocephalus eyresii* (Pisces: Atherinidae). *Proceedings of the Linnean Society of New South Wales* **112**, 87-103.
- & — (1990b) A second hardyhead, *Craterocephalus gloveri* (Pisces: Atherinidae), from Dalhousie Springs, central Australia. *Ichthyological Exploration of Freshwaters* **1**, 113-122.
- ECKERT, J. & ROBINSON, R. D. (1990) The fishes of the Coorong. *South Australian Naturalist* **65**, 4-31.
- EHMANN, H. & TYNAN, R. (1997) Wildlife management manual: the Gawler Ranges and Kingoonya Soil Conservation Districts. Department of Environment & Natural Resources, Adelaide. 174 p.
- ENVIRONMENT PROTECTION AUTHORITY (1998) State of the environment report for South Australia 1998: summary report. Department for Environment, Heritage & Aboriginal Affairs, Adelaide. 44 p.
- ENVIRONMENT PROTECTION AUTHORITY (2003) State of the environment report for South Australia 2003. Environment Protection Authority, Adelaide. 166 p.
- ESCHMEYER, W. M. (1998) "Catalog of Fishes, v 1-3" (California Academy of Sciences, San Francisco).
- FULTON, W. (1986) The Tasmanian mudfish *Galaxias cleaveri* Scott. *Journal of the Australia New Guinea Fishes Association* **4**, 150-151.
- GLOVER, C. J. M. (1979) Studies on central Australian fishes: further observations and records, part 1. *South Australian Naturalist* **53**, 58-62.
- (1980) Fishes pp. 217-223 In Corbett, D. W. P. (ed.) "A Field Guide to the Flinders Ranges" (Rigby, Adelaide).
- (1983) Freshwater and Marine Fishes pp. 157-167 In Tyler, M., Twidale, C. R., Ling, J. K. & Holmes, J. W. (eds) "Natural History of the South East" (Royal Society of South Australia, Adelaide).
- (1985) Additions to the fish fauna of South Australia. *Trans. R. Soc. S. Aust.* **109**, 59-60.
- HAMMER, M. (2002a) The south east fish inventory: distribution and conservation of freshwater fishes of south east South Australia. Native Fish Australia (SA) Inc., Adelaide. 53 p.
- (2002b) Environmental water requirements for freshwater fishes of the Marne River Catchment, South Australia. Report to River Murray Catchment Water Management Board, Adelaide. 23 p.
- , DOUBE, J. & ROBERTS, M. (2000) Conservation of the variegated pygmy perch: freshwater fish survey of lower south eastern South Australia. Report to National Parks and Wildlife SA and the South Eastern Water Conservation and Drainage Board, Adelaide. 26 p.
- HARRIS, J. H. (1995) The use of fish in ecological assessments. *Australian Journal of Ecology* **20**, 65-80.
- HICKS, D. & SHELDON, F. (1998) Biotic survey of the Wakefield River, for the Mid North Riverine Management Planning Project. Report to Department for Environment, Heritage & Aboriginal Affairs, Adelaide. Department of Zoology, University of Adelaide, South Australia. 64 p.
- HOESE, D. F., LARSON, H. K. & LLEWELLYN, L. C. (1980) Family Eleotridae, gudgeons pp. 169-185 In McDowall, R.M. (ed.) "Freshwater Fishes of South-eastern Australia" (Reed, Sydney).
- (1991) A revision of the temperate Australian Gobiid (Gobioidae) genus *Tasmanogobius* with a comment of the genus *Kimberleyeleotris*. *Memoirs of the Victorian Museum* **52**, 361-376.
- IVANSTOFF, W., CROWLEY, L. E. L. M. & ALLEN, G. R. (1987) Description of three new species and one subspecies of freshwater hardyhead (Pisces: Atherinidae: *Craterocephalus*) from Australia. *Records of the Western Australian Museum* **13**, 171-188.
- KAHRIMANIS, M. J., CURRUTHERS, S., OPPERMAN, A. & INNS, R. (2001) Biodiversity Plan for the South Australian Murray-Darling Basin. Department for Environment and Heritage, Adelaide. 356 p.
- KOEHN, J. D. & RAADIK, T. A. (1991) The Tasmanian mudfish, *Galaxias cleaveri* Scott, 1934. In Victoria. *Proceedings of the Royal Society of Victoria* **103**, 77-86.
- KOSTER, W. M., RAADIK, T. A. & CLUNIE, P. (2002) Scoping study of the potential spread and impact of the exotic fish oriental weather loach in the Murray-Darling Basin, Australia: a resource document. Freshwater Ecology, Arthur Rylah Institute for Environmental Research, Victoria. 79 p.
- KUITER, R. H. (1983) Fish in focus: Mount Gambier fishes. *Scuba Diver* **1983**, 36-41.

- LANGDON, J. S. & HUMPHREY, J. D. (1987) Epizootic haematopoietic necrosis, a new viral disease in redfin perch, *Perca fluviatilis* L., in Australia. *Journal of Fisheries Disease* **10**, 289-297.
- LARSON, H. K. (1995) A review of the Australian endemic gobiid fish genus *Chlamydogobius*, with description of five new species. *The Beagle, Records of the Museum and Art Gallery of the Northern Territory* **12**, 19-15.
- _____, & HOESE, D. F. (1996) Family Gobiidae, subfamilies Eleotridinae and Butinae: gudgeons pp. 200-219 *In* McDowall, R. M. (ed.) "Freshwater Fishes of South-eastern Australia" (Reed Books, Sydney).
- LOYD, L. N. & WALKER, K. F. (1986) Distribution and conservation status of small freshwater fish in the River Murray, South Australia. *Trans. R. Soc. S. Aust.* **100**, 49-57.
- McDOWALL, R. M. (1979) Fishes of the family Retropinnidae (Pisces: Salmoniformes) – a taxonomic revision and synopsis. *Journal of the Royal Society of New Zealand* **9**, 85-121.
- _____, & FRANKENBERG, R. S. (1981) The galaxiid fishes of Australia (Pisces: Galaxiidae). *Records of the Australian Museum* **33**, 443-605.
- MOLSHIER, R. L., GEDDES, M. C. & PATON, D. C. (1994) Population and reproductive ecology of the small-mouthed hardyhead *Atherinosoma microstoma* (Günther) (Pisces: Atherinidae) along a salinity gradient in the Coorong, South Australia. *Trans. R. Soc. S. Aust.* **118**, 207-216.
- MORGAN, D. L., HAMBLETON, S. J., GILL, H. S. & BEATTY, S. (2002) Distribution, biology and likely impacts of the introduced redfin perch (*Perca fluviatilis*) (Percidae) in Western Australia. *Marine and Freshwater Research* **53**, 1211-1221.
- MUSYL, M. K. & KEENAN, C. P. (1992) Population genetics and zoogeography of Australian freshwater golden perch, *Macquaria ambigua* (Richardson 1845) (Teleostei: Percichthyidae), and electrophoretic identification of a new species from the Lake Eyre Basin. *Australian Journal of Marine and Freshwater Research* **43**, 1585-1601.
- NATIONAL LAND & WATER RESOURCES AUDIT (2001) Australian water resources assessment, 2000: surface water and groundwater – availability and quality. National Land & Water Resources Audit, Land & Water Australia, Canberra. 160 p.
- PIERCE, B. (1990) Murray cod invade South Australia's Cooper Creek. *SAFISH* **15**, 11.
- _____, (1997) "Fair go" for endangered eight. *Southern Fisheries* **5**, 12-13.
- PIERCE, B. E. (1992) Australian bass reach the Murray in South Australia. *SAFISH* **17**, 11-12.
- _____, LLOYD, L. N. & HORNE, P. (1985) The biology of Blue Lake. *South Australian Naturalist* **59**, 63-66.
- _____, YOUNG, M. & SIM, T. (2001) Flinders Ranges fishes pp. 25-33 *In* Brandle, R. (ed.) "A Biological Survey of the Flinders Ranges, South Australia 1997-1999" (Department for Environment & Heritage, Adelaide).
- RAADIK, T. (2001) When is a mountain galaxias not a mountain galaxias? *Fishes of Sahul* **15**, 785-789.
- REID, J. R. W. & PUCKRIDGE, J. T. (1990) Coongie Lakes pp. 119-131 *In* Tyler, M. J., Twidale, C. R., Davies, M. & Wells, C. B. (Eds) "Natural History of the North-east Deserts" (Royal Society of South Australia, Adelaide).
- REYNOLDS, L. F. (1983) Migration patterns of five fish species in the Murray-Darling River system. *Australian Journal of Marine and Freshwater Research* **34**, 857-871.
- SCOTT, T. D., GLOVER, C. J. M. & SOUTHICOTT, R. V. (1974) "The Marine and Freshwater Fishes of South Australia" 2nd Edn (Government Printer, Adelaide).
- SIM, T. (2000) Freshwater fishes pp. 129-134 *In* Robinson, A. C., Casperson, K. D. & Hutchinson, M. N. (eds) "A List of the Vertebrates of South Australia" (Department for Environment & Heritage, Adelaide).
- _____, POTTS, L., HAMMER, M. & DOUBE, J. (2000) Fishes pp. 97-108 *In* "Natural History of Strathalbyn and Goolwa Districts" (Douglas Press, Woodville North, South Australia).
- SINCLAIR KNIGHT MERZ (2002) Determination of environmental water requirements of the Onkaparinga River Catchment, technical report V: fish survey. Sinclair Knight Merz P/L, Armadale, Victoria. 17 p.
- STRAHAN, R. (1980) Families Mordaciidae and Geotriidae pp 38-43 *In* McDowall, R.M. (ed.) "Freshwater Fishes of South-eastern Australia" (Reed, Sydney).
- UNMACK, P. J. (2000) The genus *Hypseleotris* of southeastern Australia: its identification and breeding biology. *Fishes of Sahul* **14**, 645-656.
- _____, (2001) Biogeography of Australian freshwater fishes. *Journal of Biogeography* **28**, 1053-1089.
- WAGER, R. & UNMACK, P. J. (2000) "Fishes of the Lake Eyre Catchment of Central Australia" (Department of Primary Industries and Queensland Fisheries Service, Brisbane).
- WAITE, E. R. (1923) "The Fishes of South Australia" (Government Printer, Adelaide).
- WATERS, J. M., SHIRLEY, M. & CLOSS, G. P. (2002) Hydroelectric development and translocation of *Galaxias brevipinnis*: a cloud at the end of the tunnel? *Canadian Journal of Fisheries and Aquatic Sciences* **59**, 49-56.
- WEDDERBURN, S. & HAMMER, M. (2003) The Lower Lakes fish inventory: distribution and conservation of freshwater fishes of the Ramsar Convention wetland at the terminus of the Murray Darling Basin, South Australia. Native Fish Australia (SA) Inc., Adelaide. 38 p.
- WILLIAMS, W. D. (1967) The chemical characteristics of lentic surface waters in Australia pp 18-77 *In* Weatherley, A. H. (ed.) "Australian Inland Waters and Their Fauna" (Australian National University Press, Canberra).
- ZIETZ, A. H. (1902) List of the edible fish of the lower Murray. *Trans. R. Soc. S. Aust.* **26**, 265-267.

**THIRTEEN NEW DYTISCIDAE (COLEOPTERA) OF THE
GENERA BOONGURRUS LARSON, TJIRTUDESSUS WATTS &
HUMPHREYS AND NIRRIPIRTI WATTS AND HUMPHREYS,
FROM UNDERGROUND WATERS IN AUSTRALIA**

By C. H. S. WATTS & W. F. HUMPHREYS†*

Summary

Watts, C. H. S. & Humphreys, W. F. 2004. Thirteen new Dytiscidae (Coleoptera) of the genera Boongurrus Larson Tjirtudessus Watts & Humphreys and Nirripiriti Watts & Humphreys, from underground waters in Australia. Trans. R. Soc. S. Aust. 128(2), 99-129, 30 November, 2004.

Thirteen new species of stygobitic Dytiscidae from inland Western Australia are described: Tjirtudessus hillviewensis sp. nov., T. microocula sp. nov., T. occidentalis sp. nov., T. padburyensis sp. nov., T. wogarthaensis sp. nov., Nirripiriti arachnoides sp. nov. N. bulbus sp. nov., N. byroensis sp. nov., N. copidotibiae sp. nov., N. dingbatensis sp. nov. N. eurypleuron sp. nov. N. innouendyensis sp. nov., and N. verrucosus sp. nov. This brings the total of stygobitic Dytiscidae described from Australia to 55, derived from 33 discrete groundwater calcretes in 8 palaeodrainages.

Key Words: Coleoptera, Dytiscidae, Stygobitic, Descriptions, New Species, Water chemistry.

THIRTEEN NEW DYTISCIDAE (COLEOPTERA) OF THE GENERA *BOONGURRUS* LARSON, *TJIRTUDESSUS* WATTS & HUMPHREYS AND *NIRRIPIRTI* WATTS AND HUMPHREYS, FROM UNDERGROUND WATERS IN AUSTRALIA.

by C. H. S. WATTS* & W. F. HUMPHREYS†

Summary

WATTS, C. H. S. & HUMPHREYS, W. F. 2004. Thirteen new Dytiscidae (Coleoptera) of the genera *Boongurrus* Larson *Tjirtudessus* Watts & Humphreys and *Nirripiriti* Watts & Humphreys, from underground waters in Australia. *Trans. R. Soc. S. Aust.* 128(2), 99-129, 30 November, 2004.

Thirteen new species of stygobitic Dytiscidae from inland Western Australia are described: *Tjirtudessus hillviewensis* sp. nov., *T. microocula* sp. nov., *T. occidentalis* sp. nov., *T. padburyensis* sp. nov., *T. wogarthensis* sp. nov., *Nirripiriti arachnoides* sp. nov., *N. bulbus* sp. nov., *N. byroensis* sp. nov., *N. copidotibiae* sp. nov., *N. dingbatensis* sp. nov., *N. eurypleuron* sp. nov., *N. innouendyensis* sp. nov., and *N. verrucosus* sp. nov. This brings the total of stygobitic Dytiscidae described from Australia to 55, derived from 33 discrete groundwater calcretes in 8 palaeodrainages. One species, *T. microocula* sp. nov., has partial eyes and wings that are only slightly reduced. *Boongurrus occidentalis* sp. nov. was collected from both surface and underground water and is little modified for an underground existence. Geographically the new species extend the range of stygobitic Dytiscidae in Australia to the Murchison and Moore drainage systems both of which drain to the Indian Ocean. Chemical and physical characters of the groundwater in some of the calcretes in which the new species were found are given.

KEY WORDS: Coleoptera. Dytiscidae. Stygobitic. Descriptions. New species. Water chemistry.

Introduction

This is the sixth paper in our series describing the stygobitic Dytiscidae of Australia (Watts and Humphreys 1999, 2000, 2001, 2003; Balke *et al.* 2004). In it we describe the new species found during fieldwork in Western Australia in winter 2002. Four new species in the Bidessine genus *Tjirtudessus* Watts & Humphreys, and 8 in the Hydroporine genus *Nirripiriti* Watts and Humphreys, are described from the westerly-draining Murchison and Moore paleodrainage systems. A new species of the genus *Boongurrus* Larson is described from material collected mainly from interstitial sand/gravels in seasonal creeks in the Pilbara but also from three bore holes accessing two different underground calcretes. This new *Boongurrus* species is fully sighted and winged and shows little apparent physical adaptation to a hyporean existence yet was found together with a true stygobitic fauna in deep calcrete.

For the first time in Australia two stygobitic species (only one described here due to lack of a male specimen in one species) were discovered with a true eye remnant, as distinct from the usual small sclerite or short suture line, and wings that, although rather small, still retain veins and folded tips

suggesting that they are at an earlier stage of adaptation to underground life than the other species so far discovered.

Geographically the new finds extend the known distribution of stygal Dytiscidae some 300 kilometres to the west. We also recollected sites in the Northern Territory that yielded stygal Dytiscidae in 2001 without discovering any additional species. In addition, areas of groundwater calcretes near The Granites, Tennant Creek and in the Amadeus basin in the Northern Territory were sampled extensively without finding any Dytiscidae and only a sparse stygobitic fauna (Syncarids, Copepods, Amphipods) at the occasional site. Although too early to be sure the results suggest that the Australian stygobitic dytiscid fauna is restricted to inland Western Australian and the Ngalia basin in central Australia.

The prime aim of this series of papers is to formally describe the dytiscid fauna and to provide a preliminary indication of the ground water characteristics in which they are found. Companion papers by and with co-workers are starting to address questions of phylogeny and evolution (Balke *et al.* 2003, Cooper *et al.* 2002, Leys *et al.* 2003) and the taxonomic composition of the rich fauna associated with the beetles (Taiti and Humphreys 2001, Karanovic and Marmonier 2002, Karanovic 2004).

Materials and Methods

The collection methods and measurements of

* C. H. S. WATTS, South Australian Museum, North Terrace, Adelaide, South Australia 5000.

† W. F. HUMPHREYS, Western Australian Museum, Francis Street, Perth, Western Australia 6000.

physico-chemical parameters in the water largely follow those used previously (Watts and Humphreys 2000) except that the use of a Quanta-G (Hydrolab Corporation, Austin, Texas) water quality monitoring system attached to a 50 m cable permitted the measurement of various physico-chemical water quality parameters (temperature, specific conductance (or TDS), pH, dissolved oxygen (% saturation or mg L^{-1}), oxidation-reduction potential (redox), and depth, the latter facilitating the determination of any vertical stratification present in the water column in some boreholes. The instrument was calibrated against the standards recommended for the instrument.

Abbreviations used:

- BES Prefix for field numbers, WAM
Biospeleology.
SAMA South Australian Museum, Adelaide.
WAM Western Australian Museum, Perth.
MB Groundwater monitoring bore.

Systematics

Key to Australian species of stygobitic Dytiscidae

- 1 — Scutellum well developed; length 4.5 mm
Copelatus abditus Balke *et al.*
- Scutellum absent; length 1.0 to 4.9 mm ..2
- 2 (1) — Paramere one-segmented; metatibia approximately the same width throughout; without pronotal plicae (Hydroporini)34
- Paramere two-segmented; metatibia narrow at base then strongly expanding towards apex; usually with pronotal plicae (Bidessini)3
- 3 (2) — With eyes4
- Without eyes, may have a small chitinized plate or suture line where eyes normally are5
- 4 (3) — Eyes of normal size; with elytral plicae ..
.....*Boongurrus occidentalis* sp. nov.
- Eyes approximately one-fifth normal size; without elytral plicae
.....*Tjirtudessus microocula* sp. nov.
- 5 (4) — Body length approximately 1.0 mm; legs stout, without swimming-hairs on fore and midlegs*Kintinka kurutjutu*
Watts and Humphreys
- Body length > 1.2 mm; legs normal, all with swimming-hairs6
- 6 (5) — Mesofemur with spines on hind edge approximately the same strength as those on mesotrochanter; length > 3.0 mm...29
- Mesofemur with spines on hind edge much more robust than those on mesotrochanter; length 1.4 – 3.6 mm....7
- 7 (6) — Normal ventrites 1 and 2 without suture between them (ie. number of visible abdominal segments reduced to four) (Fig. 82); length 3.2 – 3.6 mm.....
.....*Tjirtudessus sweetwatersensis*
Watts and Humphreys
- Ventrites 1 and 2 with suture between them, at least in inner portion (Figs 83–86); length 1.3 – 3.2 mm8
- 8 (7) — Pronotal plicae strong, well marked, excavated on inside9
- Pronotal plicae weak, difficult to trace, may be absent, not excavated on inside .
.....13
- 9 (8) — Mesosternum with posterior portion triangular in midline (Figs 77, 79).....10
- Mesosternum with posterior portion rounded in midline (Fig. 78).....11
- 10 (9) — Prosternal process rounded at tip (Fig. 75); tip of metatrochanter pointed; lobe on apical segment of paramere short.....
.....*Tjirtudessus morgani* (Watts and Humphreys)
- Tip of prosternal process pointed (Fig. 76); apex of metatrochanter rounded; lobe on apical portion of paramere long..
.....*Tjirtudessus bialveus* Watts and Humphreys
- 11 (9) — Head broad, deflexed, metatrochanter round; setae on mesofemur long.....
.....*Tjirtudessus silus* Watts and Humphreys
- With none of above characters12
- 12 (11) — Combined length of first two segments of metatarsus > rest; eye remnant present as small oval or triangular structure; paramere with long apical lobe.....
.....*Tjirtudessus pulpa*
(Watts and Humphreys)
- Combined length of first two segments of metatarsus approximately equal to rest; eye remnant reduced to single short suture; paramere with small apical lobe .
.....*Tjirtudessus cunyuensis*
Watts and Humphreys
- 13 (8) — Elytron with row of large punctures adjacent to suture26
- Elytron without sutural punctures, other than a few weak ones near base14
- 14 (13) — Eye remnant present as a small oval or triangular structure23
- Eye remnant reduced to single short suture15
- 15 (14) — Mesofemur with 5 to 7 spines on hind edge in basal half16
- Mesofemur with 2 to 4 spines on hind edge in basal half19

- 16 (15) — Protibia thick (Fig. 73); protarsus moderately expanded, mesotarsus less so; mesotibia slightly angular *Bidessodes gutteridgei* Watts and Humphreys
Protibia thin (Fig. 74); protarsus and mesotarsus approximately the same size; mesotibia not angular 17
- 17 (16) — Length 2.5 – 2.7 mm; suture between ventrites 1 and 2 complete (Fig. 83).....
..... *Tjirtudessus padburyensis* sp. nov.
Length 1.6 – 2.0 mm; suture between ventrites 1 and 2 obliterated laterally (Figs 84-86)..... 18
- 18 (17) — Paramere with lobe as wide as rest of apical segment, flat on top, expanded slightly at tip *Tjirtudessus masonensis* Watts and Humphreys
Paramere with lobe shorter than rest of apical segment, rounded on top, tip pointed *Tjirtudessus yuimmeryensis* Watts and Humphreys
- 19 (15) — Mesofemur with four spines near base; antenna with segments 1 and 3 of similar length, segment 11 approximately 1.5x length of segment 10; length 2.1 – 2.4 mm *Tjirtudessus cueensis* (Watts and Humphreys)
Mesofemur with two to three strong spines on hind edge near base; antenna with segment 2 large, oval; segment 3 much smaller and thinner, segment 11 approaching 2x length of segment 10; length 1.3 – 1.8 mm 20
- 20 (19) — Mesofemur with two strong spines on hind edge near base; paramere with apical segment with two finger-like projections *Tjirtudessus pinnaclesensis* (Watts and Humphreys)
Mesofemur with three strong spines on hind edge near base; paramere with apical segment with one finger-like projection... 21
- 21 (20) — Mesofemur with three spines grouped together near base *Tjirtudessus fridaywellensis* (Watts and Humphreys)
Mesofemur with two spines near base and one more distant 22
- 22 (21) — Pro and mesotibia club-shaped; antenna with middle segments enlarged a little on inside *Tjirtudessus hinkleri* (Watts and Humphreys)
Pro and mesotibia elongate/triangular in shape; middle segments of antenna virtually symmetrical *Tjirtudessus karalundiensis* Watts and Humphreys
- 23 (14) — Pronotum not constricted at base; prosternal process reaching or almost reaching mesosternum; 1.4 mm long
..... *Tjirtudessus wilunaensis* Watts and Humphreys
- Pronotum moderately constricted at base; prosternal process not reaching mesosternum; 2.3 – 3.2 mm long 24
- 24 (23) — Mesofemur with 6 spines close to base on hind edge *Tjirtudessus bigbellensis* (Watts and Humphreys)
Mesofemur with 3 to 6 spines spread out along basal half of hind edge 25
- 25 (24) — Suture line between ventrites 1 and 2 well marked (Fig. 83); aedeagus with medial lobe parallel sided, apex not upturned
..... *Tjirtudessus challaensis* (Watts and Humphreys)
Suture lines between ventrites 1 and 2 weak (Fig. 84), usually obsolete in lateral half; aedeagus with medial lobe distinctly narrower in middle, apex upturned
..... *Tjirtudessus jundeeensis* Watts and Humphreys
- 26 (13) — Distinct oval eye remnant present 27
— Eye remnant reduced to single short suture 28
- 27 (26) — Metatrochanter with tip slightly pointed (Fig. 11); sutural lines between ventrites 1 and 2 complete, distinct *Tjirtudessus hillviewensis* sp. nov.
Metatrochanter with tip rounded; suture between ventrites 1 and 2 obliterated laterally *Tjirtudessus windarraensis* (Watts and Humphreys)
- 28 (26) — Mesofemur with 3 spines on hind edge (Fig. 28); suture between ventrites 1 and 2 complete; metatrochanter elongate (Fig. 29) ... *Tjirtudessus wogarthaensis* sp. nov.
Mesofemur with 5 to 6 spines on hind edge; suture between ventrites 1 and 2 obliterated laterally; metatrochanter rounded *Tjirtudessus lapostaae* (Watts and Humphreys)
- 29 (6) — Mesofemur with spines arranged in two comb-like rows along hind edge from base to apex; mesotibia thin, curved
..... *Bidessodes limestoneensis* Watts and Humphreys
Mesofemur with spines on hind edge spaced out, not dense and comb-like; mesotibia straight 30
- 30 (29) — Pro and mesotarsus with basal segment much more expanded than other segments 31
— Pro and mesotarsus with basal segment only moderately expanded compared with other segments 32
- 31 (30) — Antenna with segments 8 to 11 noticeably

- thinner than others, segment 3 longer than segment 2...*Tjirtudessus magnificus* Watts and Humphreys
- Antenna with segments 8 to 10 not noticeably thinner than others, segment 3 same length as segment 2....*Tjirtudessus macrotarsus*. Watts and Humphreys
- 32 (30) — Pronotum a little narrower than elytra; length 3.5 – 5.0mm33
Pronotum wider than elytra; length 3.2 – 3.5mm*Tjirtudessus eberhardi* Watts and Humphreys
- 33 (32) — Metatrochanter rounded at tip; aedeagus with central lobe straight, tip pointed; eye remnant small...*Tjirtudessus raesideensis* Watts and Humphreys
Metatrochanter pointed at tip; aedeagus with central lobe twisted, tip knobbed; without eye remnant...*Tjirtudessus hahni* Watts and Humphreys
- 34 (2) — From the Northern Territory35
From Western Australia39
- 35 (34) — Head short, very broad, strongly deflexed; pronotum strongly narrowed at base; prosternal process anvil-shaped.....
.....*Nirripirti macrocephalus* Watts and Humphreys
- Head variably shaped, not deflexed, base of pronotum variably shaped; prosternal process "normally" shaped36
- 36 (35) — Protarsus with segment 3 not bilobed; pronotum not constricted at base; antenna thin, segments 1 and 2 subequal.....
.....*Nirripirti pentameres* Watts and Humphreys
Protarsus with segment 3 bilobed; pronotum weakly to moderately constricted at base; antenna thick, segment 2 much broader than segment 137
- 37 (36) — Length 1.8 mm; body well-chitinized
.....*Nirripirti napperbyensis* Watts and Humphreys
Length 1.2 – 1.6 mm; body weakly chitinized.....38
- 38 (37) — Length 1.2 mm; body only slightly constricted at junction of pronotum and elytra*Nirripirti wedgeensis* Watts and Humphreys
- Length 1.5 mm; body quite strongly constricted at junction of pronotum and elytra*Nirripirti newhavenensis* Watts and Humphreys
- 39 (34) — Pronotum (and head) about half width of elytra (Fig. 36)*Nirripirti arachnoides* sp. nov.
- Pronotum > three quarters width of elytra
- 40 (39) — Elytron with visible ventral portion extensive except close to apex (eg. Fig. 85)41
Elytron with visible ventral portion narrow except in basal quarter (eg. Fig. 86)45
- 41 (40) — Length 3.6 – 3.8 mm.....*Nirripirti stegastos* Watts and Humphreys
- Length 1.5 – 2.5 mm.....42
- 42 (41) — Antenna with segments 6 to 8 greatly expanded, much broader than segments 9 and 10 (Fig. 42)
.....*Nirripirti bulbis* sp. nov.
Antenna with segments 6 to 10 of approximately equal size43
- 43 (42) — Meso and metatibia elongate triangular; body strongly boat-shaped, pronotum much narrower in front44
Meso and metatibia cylindrical (Figs 61, 62); front and rear of pronotum same width (Fig. 63)*Nirripirti eurypleuron* sp. nov.
- 44 (43) — Length 2.1 to 2.3 mm; metatrochanter with tip sharply pointed*Nirripirti skaphites* Watts and Humphreys sp. nov.
Length 1.5 to 1.9 mm; metatrochanter with tip rounded*Nirripirti killaraensis* Watts and Humphreys
- 45 (40) — Antenna with segment 2 larger and more oval than segment 1; 1.2 – 2.1 mm long .
.....52
- Antenna with segment 2 more or less the same shape as segment 1 or smaller; 2.5 – 3.9 mm long46
- 46 (45) — Mesofemur with row of about 20 closely placed small spines along hind edge (Fig. 43)*Nirripirti byroensis* sp. nov.
- Mesofemur with 10 or fewer weak to very strong spines along hind edge47
- 47 (46) — Metasternal plate parallel sided (Fig. 80); mesofemur with 8 to 10 spines, closely placed, very strong; metatrochanter long and thin about 4 x as long as wide
.....*Nirripirti fortisspina* Watts and Humphreys
- Metasternal plate narrowing towards rear (eg. Fig. 81); mesofemur with 4 to 8 spines, weak to moderately strong; metatrochanter moderately elongate 2 to 2.5 x as long as wide48
- 48 (47) — Metatarsus with segment 1 as long as others combined, with confluent group of 5 strong spines in middle on outside (Fig. 51).....*Nirripirti copidotibiae* sp. nov.
Metatarsus with segment 1 much shorter than others combined, without confluent

- group of spines on outside.....49
- 49 (48) — Metasternal plate without wings (Fig. 81)
.....*Nirripiriti plutonicensis*
Watts and Humphreys
- Metasternal wings obvious but short (eg.
Fig. 80)50
- 50 (49) — Metafemur with 2 to 4 small lumps on top
edge (Fig. 71)*Nirripiriti verrucosus*
sp. nov.
- Metafemur with smooth top edge.....51
- 51 (50) — Mesofemur with moderately strong
spines; metacoxal plate nearly reaching
mesocoxae.....*Nirripiriti hinzeae*
Watts and Humphreys
- Mesofemur with thin spines; metacoxal
plate at least the width of metafemur from
mesocoxae.....*Nirripiriti darlotensis*
Watts and Humphreys
- 52 (45) — Elytron with shoulder flared outwards
(Fig. 86)*Nirripiriti hamoni*
Watts and Humphreys
- Elytron with shoulder not flared (eg. Fig.
85)53
- 53 (52) — Metatrochanter produced into long strong
point (Fig. 68)*Nirripiriti*
innouendyensis sp. nov.
- Metatrochanter rounded, at most bluntly
pointed.....54
- 54 (53) — Eye remnant absent; metatrochanter
large, squat; hind leg stout; length 1.2
mm. *Nirripiriti milgunensis*
Watts and Humphreys
- Eye remnant represented by a short suture
at side of head; metatrochanter elongate;
hind leg elongate; length 1.8 - 2.0 mm....
.....*Nirripiriti melroseensis*
Watts and Humphreys

Descriptions

The following species descriptions are grouped in alphabetical order under genus which are placed in the order *Boongurrus*, *Tjirtudessus*, *Nirripiriti*.

Boongurrus Larson (Hydroporinae, Bidessini)

Boongurrus occidentalis sp. nov.

FIGS 13-18

Holotype

m: '10 K NW Eerala Stn CHS Watts 23/5/01', WAM 34222. Card mounted.

Paratypes

25; 8, as for holotype, SAMA; 12, 'Wittenoom Gorge Town Pool CHS & GA Watts 26/5/01', 10 SAMA, 2, Lars Hendrich collection (Berlin); 1, 'BES 9277 Killara Station north, unused water bore, 26°

03' 55" S 118° 41' 58" E, 6/6/2002 W. F. Humphreys and R. Leys', SAMA; 1, 'BES 9318 Moorarie Stn nr calcrete quarry site 419, 25° 52' 26S 117° 27' 09E, 8/6/02, W. F. Humphreys & R. Leys', SAMA; 2, ditto except 'BES 9320', 1 WAM 34177, 1 SAMA; 1, 'BES 9246 Wagga Wagga Stn, mineral exploration bore 28° 26' 36" S 116° 38' 9" E, 4/6/02, W. F. Humphreys & R. Leys', SAMA.

Description (number examined, 24)

Habitus. Length 1.9 – 2.3 mm; relatively flat, weakly constricted at junction of pronotum/elytra; elongate oval; uniformly light testaceous, elytra uniformly darker; hindwing not reduced; eyes of normal size.

Head. Narrower than elytra; smooth, shiny, weak reticulation towards rear, punctures small, sparse; without cervical stria, subparallel in posterior half, widest just behind eye, antenna stout, segments 1 and 2 cylindrical, segment 3 as long as segment 2, narrower, narrowing slightly towards base, segments 4 to 8 becoming progressively slightly broader, segments 9 and 10 a little narrower than segment 8, segment 11 about twice length of segment 10, each segment, except segment 1, with some very small setae on inside apically. Maxillary palpus elongate, segment 4 as long as segments 1 to 3 combined.

Pronotum. A little narrower than elytra; anteriolateral angles projecting strongly forward; base weakly constricted, posteriolateral angles square, surface slightly rugose, with moderately dense, moderately sized punctures and a row of stronger punctures along front margin; basal plicae strong, excavated somewhat on inside, converging slightly towards front, reaching to about two-thirds way along pronotum.

Elytra. Not fused, with weak inner ridges near apex (ligula), lacking in some; elongate, nearly parallel-sided in middle; rugose, quite densely covered with moderate sized punctures; plicae well impressed, straight, about as long as pronotal plicae. Epipleuron well differentiated from rest of elytra particularly anteriorly, lacking basal carina, relatively broad in anterior quarter then progressively narrowing to near apex.

Ventral surface. Prosternal process strongly narrowed between coxae, reaching mesothorax, apical half elongate triangular, weakly arched in lateral view with highest point (viewed ventrally) between coxae. Mesocoxae separated. Metathorax strongly triangular in front in midline; wings short; broadly rounded in midline behind. Metacoxal plates large, quite strongly punctate, moderately rugose, metacoxal lines distinct, moderately widely spaced, reaching to metasternum, weakly diverging; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct, ventrites 3 to 5 mobile, rugose,

well covered with moderate sized seta-bearing punctures.

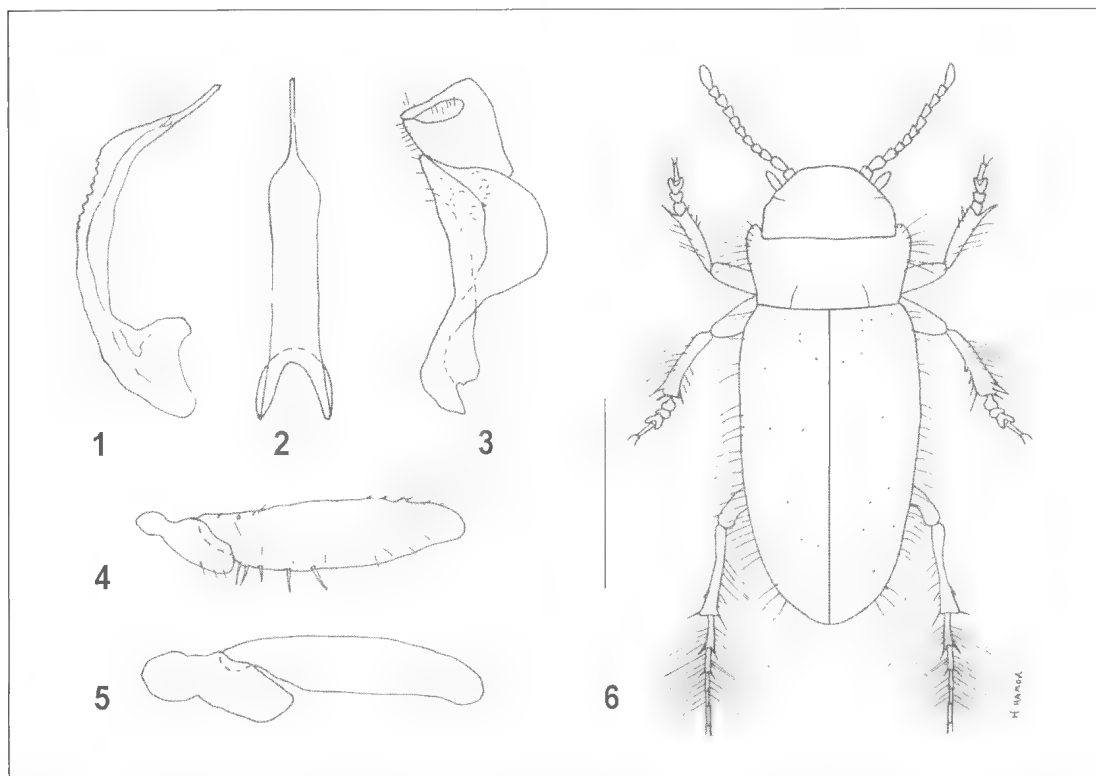
Legs. Protibia triangular, outer edge bow-shaped, widest towards apex where it is about four times its basal width; protarsus weakly expanded, segment 1 as broad as long, segment 2 as wide as segment 1 and about half its length, segment 3 as long as segment 1 and a little narrower, deeply bifid, segment 4 very small, hidden within lobes of segment 3, segment 5 narrow, cylindrical, about 1.5x length of segment 3, segments 1 to 3 with dense covering of adhesive setae; claws short and simple. Mesotrochanter elongate-oval with a few relatively long, thin setae on inner edge; mesofemur with 4 to 5 moderately strong setae in basal half, only slightly stronger than those on other parts of the femur (Fig. 16), mesotarsus slightly less expanded than protarsus. Metatrochanter tip rounded (Fig. 17); metafemur relatively stout, lacking spines; metatibia narrow, moderately curved, widening towards apex; metatarsi relatively stout, segment 1 longest, segment 5 longer than segment 4, segments 1 and 2 in combination about as long as others; claws weak.

Male

Little external differentiation between the sexes. Median lobe of aedeagus broad in middle narrowing to sharp point; paramere broad, apical segment with relatively stout apical lobe well separated from rest of segment. Figs 13-14.

Remarks

This new species of *Boongurrus* closely resembles *B. rivulus* (Larson) from the Atherton tableland region of north Queensland differing externally only in the larger eyes, slightly less rugose body, slightly weaker tarsi and thinner antennae. The main differentiating characters are the size of the eyes which in the new species are of normal epigeal size in contrast to those of *B. rivulus* which are about three quarters normal size and in the male genitalia. The aedeagus of *B. occidentalis* is broader medially and tapers to a longer and sharper point. The apical segment of the paramere is longer than in *B. rivulus* and the apical lobe smaller but much more distinct (Larson 1994).



Figs 1-6. *Tjirtudessus hillviewensis*: 1, lateral view of central lobe of aedeagus; 2, ditto dorsal view; 3, paramere; 4, mesotrochanter and mesofemur; 5 metatrochanter and metafemur; 6, dorsal view. Scale bar represents 1mm (habitus only).

Most of the specimens have been collected at the edge of pools in sandy riverbeds and interstitially to at least two meters from the water's edge in an upstream direction. It has also been recorded as flying to light (in Australian Insect Collection CSIRO Canberra). A little surprisingly a few specimens were collected during this year's fieldwork from boreholes in two separate calcretes together with a true stygobitic fauna. The Killara North site was an open unused water bore ca 3 m to water and a water depth of ca 9 m in a calcrete area and the associated stygofauna included Bathynellacea, crangonytoid and Ceinidae Amphipoda, Harpacticoida, Cyclopoida. The Moorarie site was a sealed monitoring bore in calcrete within 30 m of a calcrete quarry that penetrated the groundwater; the borehole contained a stygobitic fauna comprising Bathynellacea and Amphipoda. DNA studies (Reinko Leys pers. com.) found no differences between *B. occidentalis* specimens collected from epigeal and stygal habitats.

Etymology

Latin. 'Occidental' - western. A reference to its distribution.

Tjirtudessus Watts & Humphreys (Hydroporinae, Bidessini)

Tjirtudessus hillviewensis sp. nov.

FIGS 1-6

Holotype

m. 'BES 9399, Hillview Station, bore at Camel Well, 26° 58' 20S 117° 27' 09" E, 13/6/02, W. F. Humphreys & R. Leys', WAM 34178. Slide mounted.

Paratype

1 (partial), as for holotype except 'BES 9398', SAMA.

Description (number examined, 1 + 1 partial)

Habitus. Length 2.35 mm; relatively flat, weakly constricted at junction of pronotum/elytra; elongate oval; uniformly light testaceous; hindwing reduced, broad, about half length of elytron, tip slightly folded; weakly sclerotized.

Head. A little narrower than elytra; smooth, reticulation weak, punctures sparse, very small; subparallel in posterior half, widest just behind eye remnant; eye remnant reduced to small triangular area. Antenna moderately stout, segments 1 and 2 broad, oval, segment 3 as long as segment 2, narrower, narrowing towards base, segments 4 to 10 subequal, segment 11 about twice length of segment 10, each segment, except segment 1, with some very small setae on inside apically. Maxillary palpus,

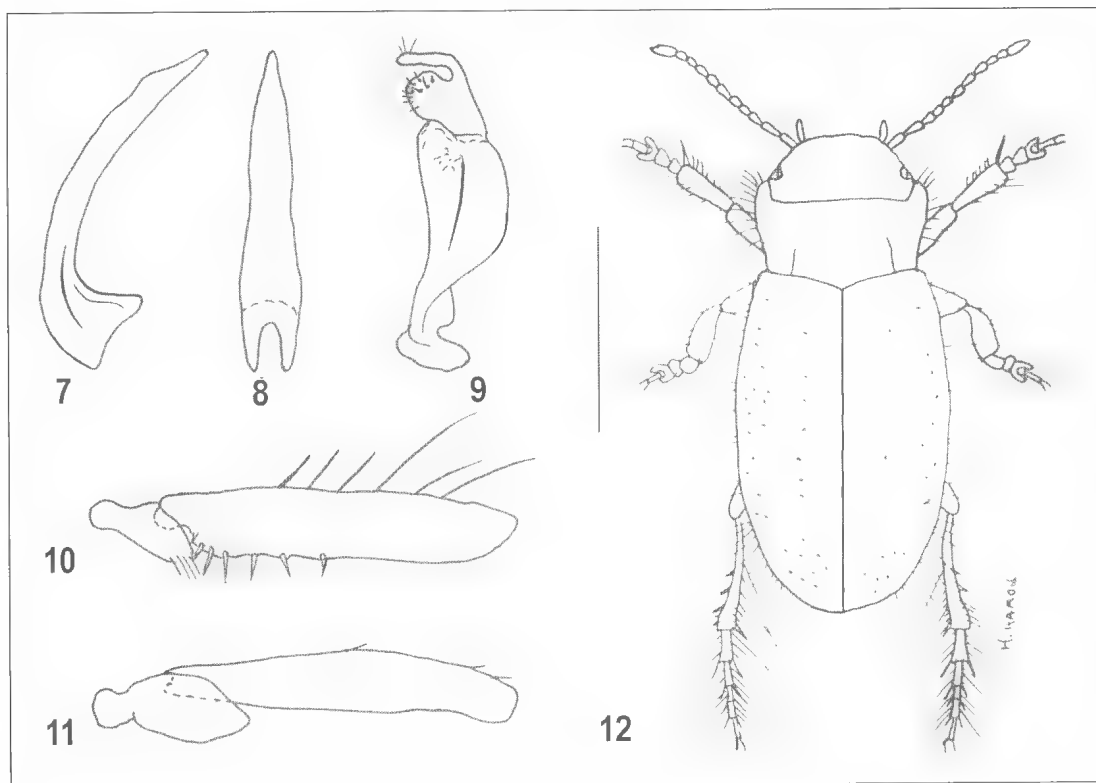
elongate, segment 4 as long as segments 1 to 3 combined.

Pronotum. About same width as elytra; anteriolateral angles projecting strongly forward; base weakly constricted, posteriolateral angles obtuse, overlying elytra somewhat; smooth, with sparse, very weak punctures and a row of stronger punctures along front margin; basal plicae moderately impressed, converging slightly towards front, reaching to about half way along pronotum; numerous long setae laterally in anterior half.

Elytra. Not fused, tightly closed, lacking inner ridges; elongate, almost parallel sided, smooth, very weakly reticulate, sparsely covered with small punctures, a few widely spaced larger punctures close to inner edge; row of long setae near lateral edge, a few additional larger punctures with long setae, more frequent towards sides and apex. Epipleuron moderately differentiated from rest of elytra, moderately broad in anterior quarter, progressively thinner till near apex.

Ventral surface. Prosternal process strongly narrowed between coxae, not reaching mesothorax, apical half broad, sides slowly converging to rounded apex, strongly arched in lateral view with highest point (viewed ventrally) between coxae. Mesocoxae in contact at midline. Metathorax broadly triangular in front in midline; wings stout, narrow; narrowly rounded in midline behind. Metacoxal plates large, weakly reticulate, metacoxal lines indistinct, moderately widely spaced, reaching to about halfway to metasternum, quite strongly diverging; a few small setae-bearing punctures towards midline; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct, ventrites 3 to 5 mobile, sparsely covered with small seta-bearing punctures, ventrites 3 and 4 with a long central seta or bunch of long setae.

Legs. Protibia bow-shaped, relatively narrow, widest towards apex where it is about four times its basal width; protarsus weakly expanded, segment 1 as broad as long, segment 2 as wide as segment 1 and about half its length, segment 3 as long as segment 1, narrower, deeply bifid, segment 4 very small, hidden within lobes of segment 3, segment 5 narrow, cylindrical, about 1.5x length of segment 3, segments 1 to 3 with very dense covering of adhesive setae; claws short and simple. Mesotrochanter elongate/oval with a few thin setae on inner edge; mesofemur with 4 evenly spaced spines in basal half (Fig. 4) mesotarsus a little more elongate than protarsus. Metatrochanter tip angular (Fig. 5); metafemur relatively stout, lacking spines; metatibia narrow, moderately curved, widening towards apex; metatarsus elongate, segment 1 longest, segment 5 a little longer than segment 4, segments 1 and 2 in combination about as long as others; claws weak.



Figs 7-12. *Tjirtudessus microocula*: 7, lateral view of central lobe of aedeagus; 8, ditto dorsal view; 9, paramere; 10, mesotrochanter and mesofemur; 11, metatrochanter and metafemur; 12, dorsal view. Scale bar represents 1mm (habitus only).

Male

Female not known. Median lobe of aedeagus with unusually long thin apical portion, slightly crenulated on top; paramere broad, apical segment with long, narrow, apical lobe separated from rest of segment except at its apex which overlaps rest of segment. Figs 1-2.

Etymology

Named after the pastoral station on which it was found.

Remarks

Most closely resembles *T. windarraensis* in size, presence of an eye remnant, row of large punctures on elytron adjacent to the suture and pointed median lobe of the aedeagus, but differs in the shorter apical segment of the paramere and larger apical lobe, as well as having a more oval eye remnant, and a complete suture between the first and second ventrites which is obliterated laterally in *T. windarraensis*.

Tjirtudessus microocula sp. nov.

FIGS 7-12

Holotype

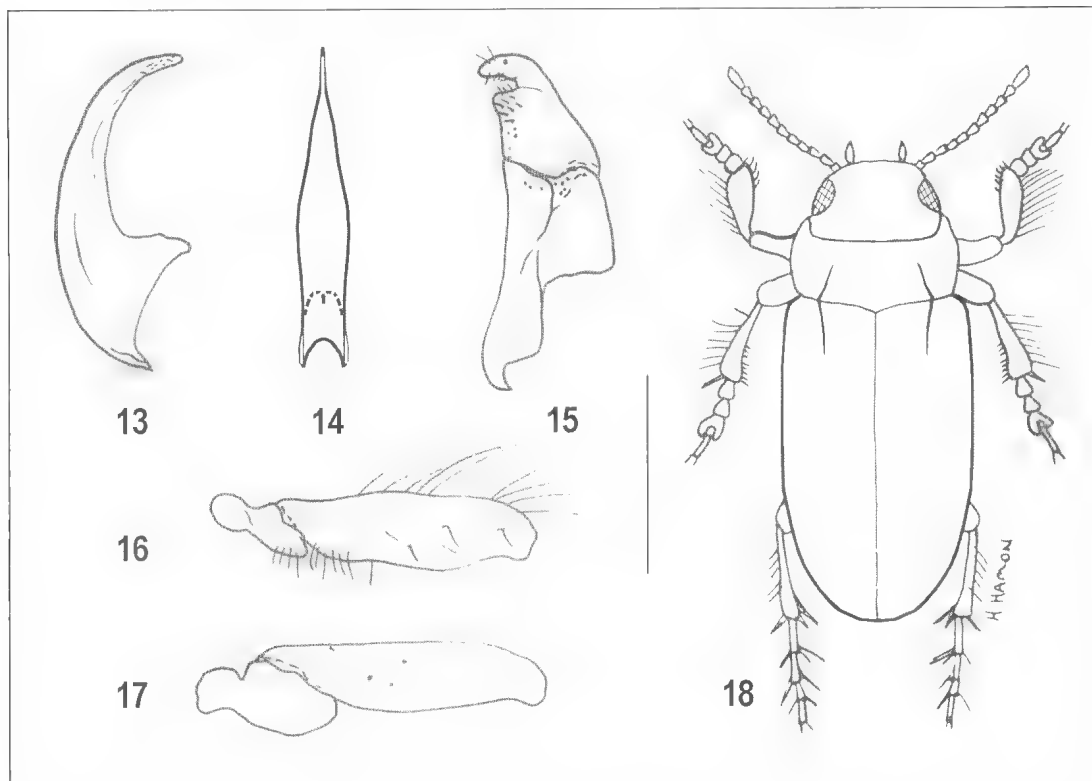
m. 'BES 9223, Bunnawarra Station, bore nr. shearing shed, 28° 36' 35" S 11° 34' 25" E, 3/6/02, W. F. Humphreys & R. Leys', WAM 34179. Slide mounted.

Paratypes

37; 19 + 5 partial specimens, as for holotype, 8 + 5 partial specimens WAM 34180 - 34192, 11 SAMA; 4, as for holotype except 'BES 9224, well near shearers quarters, 28° 36' 36" S 116° 34' 18" E', WAM 34193 - 34196; 4, as for holotype except 'BES 9225', SAMA.

Description (number examined, 38)

Habitus. Length 2.2 - 2.3 mm; relatively flat, weakly constricted at junction of pronotum/elytra; elongate oval; uniformly light testaceous; eyes reduced to about a fifth normal size; hindwing reduced, about length of elytron, tip folded.



Figs 13-18. *Boongurrus occidentalis*: 13, lateral view of central lobe of aedeagus; 14, ditto dorsal view; 15, paramere; 16, mesotrochanter and mesofemur; 17 metatrochanter and metafemur; 18, dorsal view. Scale bar represents 1mm (habitus only).

Head. Narrower than elytra; smooth, reticulation weak, punctures sparse, small; subparallel in posterior half, widest just behind eye; eye reduced to about a fifth normal size, lacking individual facets, darkly pigmented. Antenna relatively thin, segments 1 and 2 cylindrical, segment 3 as long as segment 2, narrower, narrowing towards base, segments 4 to 10 subequal, segment 11 elongate, a little less than twice length of segment 10, each segment, except segment 1, with some very small setae on inside apically. Maxillary palpus, elongate, segment 4 as long as segments 1 to 3 combined.

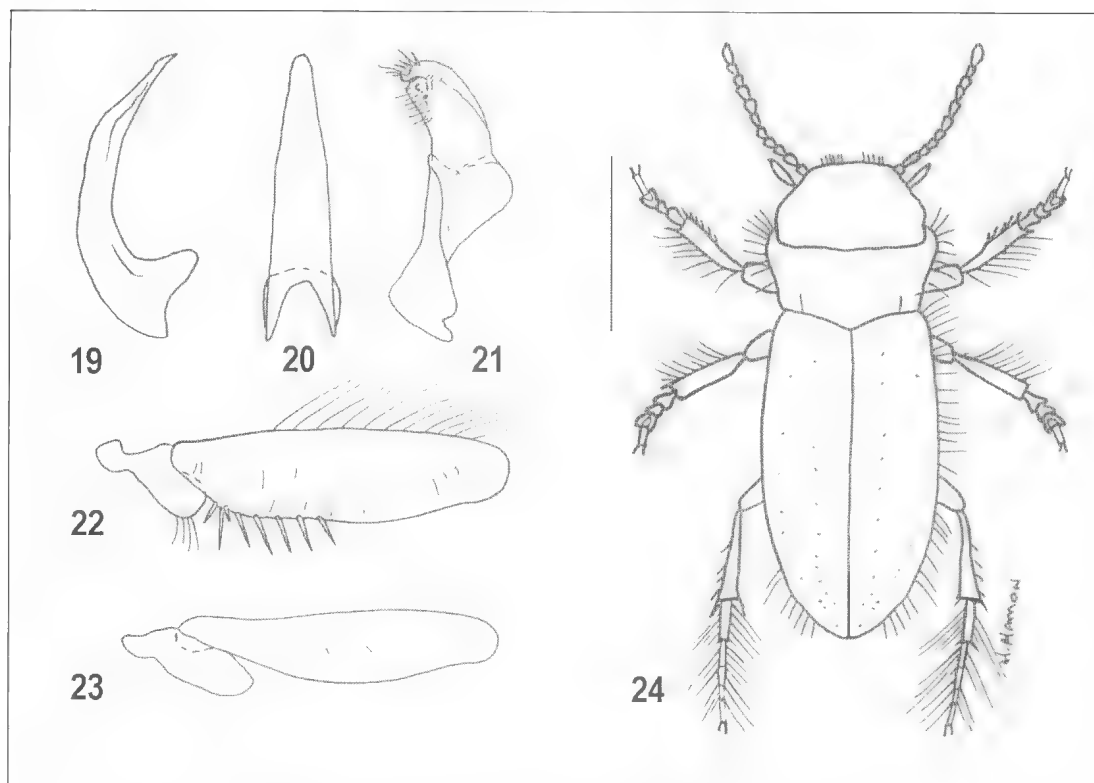
Pronotum. A little narrower than elytra; anteriolateral angles projecting strongly forward; base moderately constricted, posteriolateral angles bluntly pointed, smooth, with sparse, very weak punctures and a few stronger punctures along front margin; basal plicae weak, strongly slanting inwards, reaching to about half way along pronotum; with row of long setae laterally in anterior half.

Elytra. Not fused but tightly closed, lacking inner ridges; widest behind middle, smooth, very weakly reticulate, sparsely covered with very small

punctures, row of long setae near lateral edge, a few additional larger punctures with long setae, more frequent towards sides. Epipleuron well differentiated from rest of elytra, moderately wide in anterior fifth, virtually absent along rest of elytron.

Ventral surface. Prosternal process strongly narrowed between coxae, not reaching mesothorax, apical half elongate triangular, sides subparallel, rapidly narrowing to small blunt point posteriorly, strongly arched in lateral view with highest point (viewed ventrally) between coxae. Mesocoxae in contact at midline. Metathorax triangular in front in midline; wings narrow; broadly rounded in midline behind. Metacoxal plates large, very weakly reticulate, metacoxal lines obsolete; a few small setae-bearing punctures towards midline; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct except in lateral fifth, ventrites 3 to 5 mobile, sparsely covered with small seta-bearing punctures, ventrites 3 and 4 with a long central seta or bunch of long setae.

Legs. Protibia triangular, relatively narrow, widest



Figs 19-24. *Tjirtudessus padburyensis*: 19, lateral view of central lobe of aedeagus; 20, ditto dorsal view; 21, paramere; 22, mesotrochanter and mesofemur; 23, metatrochanter and metafemur; 24, dorsal view. Scale bar represents 1mm (habitus only).

near apex where it is about three times its basal width; protarsus expanded, segment 1 as broad as long, segment 2 as wide as segment 1 and about half its length, segment 3 as long as segment 1 much narrower, deeply bifid, segment 4 very small, hidden within lobes of segment 3, segment 5 narrow, cylindrical, about 1.5x length of segment 3, segments 1 to 3 with dense covering of adhesive setae; claws moderately long, simple. Mesotrochanter elongate/oval with a few thin setae on inner edge; mesofemur with 5 to 6 spines in basal half, basal two close together (Fig.10); mesotarsus similar to protarsus. Metatrochanter weakly pointed (Fig.11); metafemur relatively thin, lacking spines; metatibia narrow, curved, widening towards apex; metatarsus elongate, segment 1 longest, segment 5 longer than segment 4, segments 1 and 2 in combination about as long as others; claws weak.

Male

Little external difference between sexes. Median lobe of aedeagus variable in width along shaft, tip bluntly pointed; paramere broad, apical segment

with long, narrow, apical lobe well separated from rest of segment. Figs 7-8.

Etymology

Latin. 'Oculus' - eye, 'micro' - small. A reference to the small eyes in this species.

Remarks

Tjirtudessus microocula appears to be in an earlier stage of adaptation to an underground environment than the other stygal Dytiscidae previously recorded in Australia (with the exception of *Boongurrus occidentalis*, which is certainly not an obligate stygobiotic). The eyes are only about a fifth the size of those in epigeal members of the genus and do not seem to be organised into individual ommatidia. It is hard to envisage them as fully functional. As well as the presence of partial eyes *T. microocula* has wings which are still large enough to require folding and still retain veins, the prosternal process is not deflexed and reaches the metathorax hence separating the mesocoxae as in epigeal species.

Two other specimens, both female and because of that not described, of a much smaller species were collected from the same well. This species also has small remnant eyes, moderately developed wings and a prosternal process that reaches the metathorax. Biochemically they are sister species (Remko Leys pers com.).

Tjirtudessus padburyensis sp. nov.

FIGS 19-24

Holotype

m. 'BES 9329, Mt Padbury Station, Irrigation Well, site 412, 25° 41' 54" S 118° 05' 29" E, 8/6/02. W. F. Humphreys & R. Leys', WAM 34197. Slide mounted.

Paratypes

5; 1, as for holotype, SAMA; 4, as for holotype except 'BES 9330', 2 WAM 34198 - 34199, 2 SAMA.

Description (number examined, 6)

Habitus. Length 2.5 – 2.7 mm; relatively flat, moderately constricted at junction of pronotum/elytra; elongate oval; uniformly light testaceous; hindwing reduced, about length of elytron.

Head. A little narrower than elytra; smooth, reticulation weak, punctures sparse, very small; subparallel in posterior half, widest just behind eye remnant; eye remnant reduced to small semicircular area. Antenna moderately stout, segments 1 and 2 cylindrical, segment 3 as long as segment 2, narrower, narrowing towards base, segments 4 to 10 approximately equal in shape, segment 11 similar to segment 10, each segment, except segment 1, with some very small setae on inside apically. Maxillary palpus, elongate, segment 4 as long as segments 1 to 3 combined.

Pronotum. Same width as elytra; anteriolateral angles projecting strongly forward; base strongly constricted, posteriolateral angles bluntly pointed, overlying elytra somewhat; smooth, reticulation weak, punctures very weak, sparse, a row of stronger punctures along front margin; basal plicae moderate, straight, slightly excavated inwards, reaching to about half way along pronotum; with row of long setae laterally in anterior half.

Elytra. Not fused, lacking inner ridges; elongate, widest behind middle, smooth, very weakly reticulate, sparsely covered with very small punctures, a few widely spaced larger punctures close to inner edge in apical third; a few additional larger punctures with long setae, more frequent towards sides. Epipleuron not differentiated from rest of elytron, that portion of elytron visible

ventrally, relatively broad in anterior third, thin along rest of elytron.

Ventral surface. Prosternal process strongly narrowed between coxae, not reaching mesothorax, sides subparallel, tip bluntly pointed, strongly arched in lateral view with highest point (viewed ventrally) between coxae. Mesocoxae in contact at midline. Metathorax triangular in front in midline; wings narrow; rounded or slightly triangular in midline behind. Metacoxal plates large, shiny, virtually nonreticulate, metacoxal lines obsolete; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct, ventrites 3 to 5 mobile, sparsely covered with small seta-bearing punctures, ventrites 3 and 4 with a long central seta or bunch of long setae.

Legs. Protibia triangular, relatively narrow, widest near apex where it is about four times its basal width; protarsus expanded, segment 1 as broad as long, segment 2 as wide as segment 1 and about a third its length, segment 3 shorter than segment 1 much narrower, about as wide, bifid, segment 4 very small, hidden within lobes of segment 3, segment 5 narrow, cylindrical, about 1.5x length of segment 3, segments 1 to 3 with very dense covering of adhesive setae; claws short and simple. Mesotrochanter elongate/rectangular with a few thin setae on inner edge; mesofemur with 6 spines in basal half (Fig. 22); mesotarsus similar to protarsus. Metatrochanter tip rounded (Fig. 23); metafemur relatively thin, lacking spines; metatibia narrow, moderately curved, widening towards apex; metatarsus elongate, segment 1 longest, segment 5 longer than segment 4, segments 1 and 2 in combination about as long as others; claws weak.

Male

Little external differences between the sexes. Median lobe of aedeagus relatively broad, gradually narrowing towards tip, tip rounded; paramere broad, apical segment with short apical lobe overlapping rest of segment. Figs 19-21.

Etymology

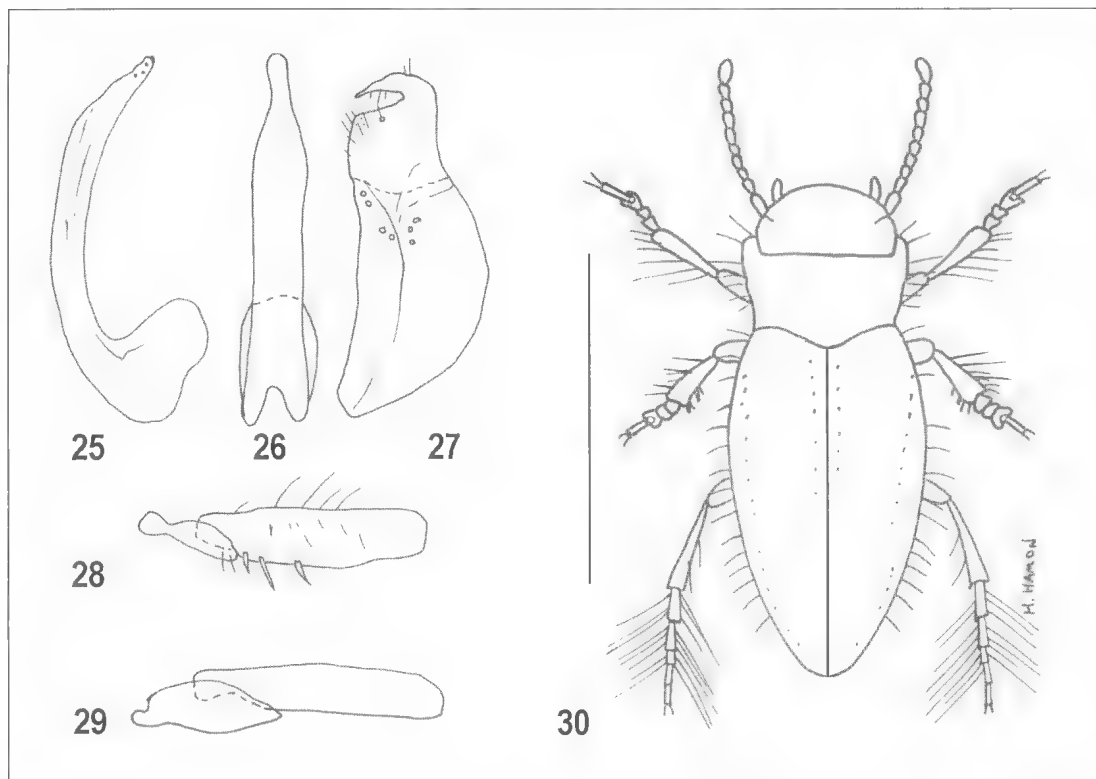
Named after the pastoral station on which it was found.

Remarks

A moderately sized very 'average' species with broad tarsi and a complete suture line between ventrites 1 and 2. The unusually small apical lobe to the paramere is shared only with *T. morgani* an otherwise very different species.

Tjirtudessus wogarthaensis sp. nov.

FIGS 25-30



Figs 25-30. *Tjirtudessus wogarthaensis*: 25, lateral view of central lobe of aedeagus; 26, ditto dorsal view; 27, paramere; 28, mesotrochanter and mesofemur; 29 metatrochanter and metafemur; 30, dorsal view. Scale bar represents 1mm (habitus only).

Holotype

m. 'BES 9384, Moorarie Station, Wogartha Well, 25° 57' 58" S 117° 35' 28" E, 12/6/02, W. F. Humphreys & R. Leys', WAM 34200. Slide mounted.

Paratype

1. as for holotype, SAMA.

Description (number examined, 2)

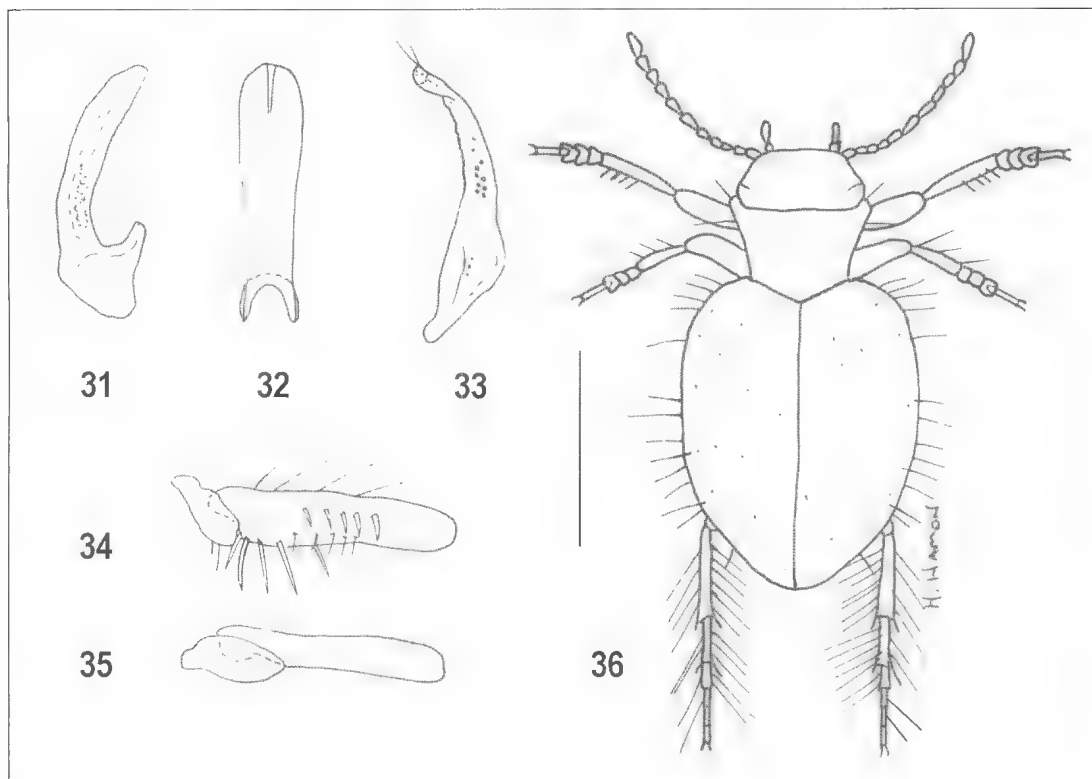
Habitus. Length 1.4 - 1.5 mm; weakly chitinated; relatively flat, moderately constricted at junction of pronotum/elytra; elongate oval; uniformly light testaceous; hindwing vestigial, about one eighth length of elytron.

Head. Considerably narrower than elytra; smooth, reticulation strong, punctures sparse, very small; subparallel in posterior half, widest just behind eye remnant; eye remnant reduced to single small suture. Antenna stout, segment 1 cylindrical, segment 2 broader, oval, segment 3 shorter than segment 2, much narrower, narrowing towards base, segments 4 to 8 becoming progressively slightly broader,

segments 9 and 10 a little narrower than segment 8, segment 11 about twice length of segment 10, each segment, except segment 1, with some very small setae on inside apically. Maxillary palpus, elongate, segment 4 as long as segments 1 to 3 combined.

Pronotum. A little narrower than elytra; anteriolateral angles projecting strongly forward; base weakly constricted, posteriolateral angles bluntly pointed, overlying elytra somewhat; smooth, reticulation strong, punctures sparse, very weak, a row of stronger punctures along front margin; basal plicae absent; with row of long setae laterally in anterior half.

Elytra. Not fused, tightly closed, lacking inner ridges; elongate, widest in middle, smooth, strongly reticulate, sparsely covered with very small punctures, row of widely spaced larger punctures close to inner edge; row of long setae near lateral edge, a few additional larger punctures with long setae, more frequent towards sides. Epipleuron indistinctly differentiated from rest of elytra, that portion of elytron visible ventrally relatively narrow, relatively even width until near apex.



Figs 31-36. *Nirridessus arachnoides*: 31, lateral view of central lobe of aedeagus; 32, ditto dorsal view; 33, paramere; 34, mesotrochanter and mesofemur; 35 metatrochanter and metafemur; 36, dorsal view. Scale bar represents 1mm (habitus only).

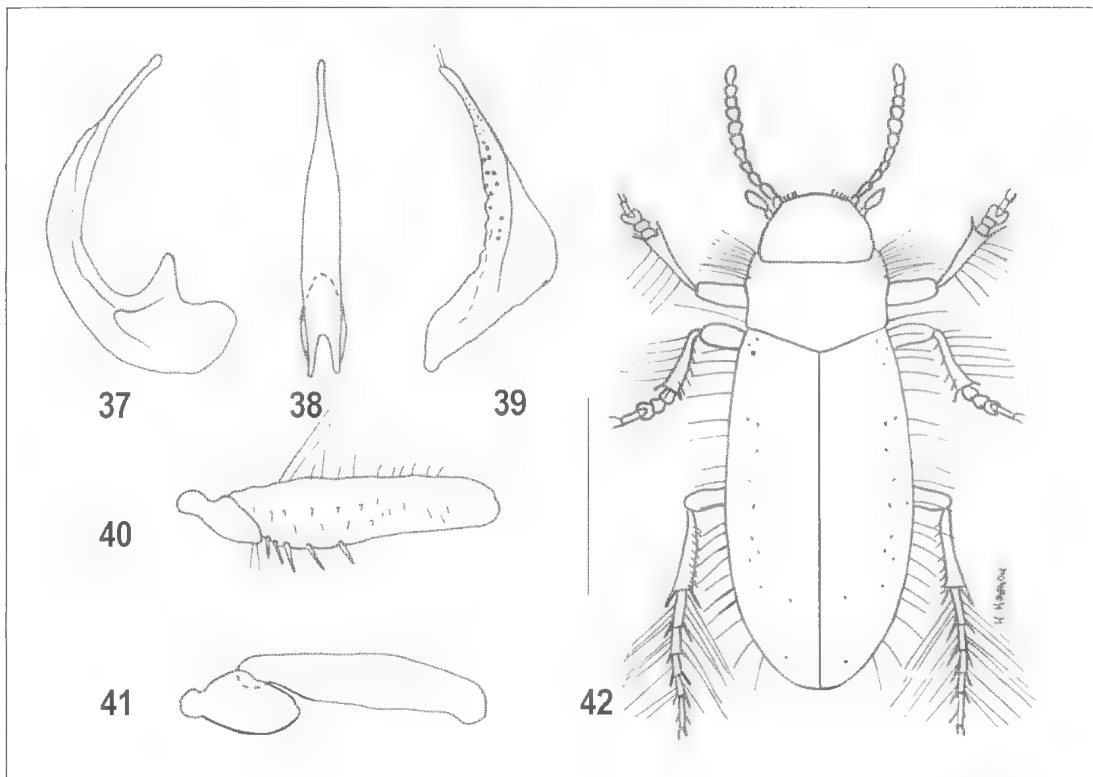
Ventral surface. Prosternal process strongly narrowed between coxae, not reaching mesothorax, apical half elongate triangular, strongly arched in lateral view with highest point (viewed ventrally) between coxae. Mesocoxae in contact at midline. Metathorax triangular in front in midline; wings narrow; narrowly rounded in midline behind. Metacoxal plates large, strongly reticulate, metacoxal lines indistinct, widely spaced, reaching to about halfway to metasternum, not diverging; a few small setae-bearing punctures towards midline; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct, ventrites 3 to 5 mobile, sparsely covered with small seta-bearing punctures, ventrites 3 and 4 with a long central seta or bunch of long setae.

Legs. Protibia triangular, moderately broad, widest near apex where it is about five times its basal width; protarsus expanded, segment 1 as broad as long, segment 2 as wide as segment 1 and about half its length, segment 3 as long as segment 1, narrower, deeply bifid, segment 4 very small,

hidden within lobes of segment 3, segment 5 narrow, cylindrical, about 1.5x length of segment 3, segments 1 to 3 with dense covering of adhesive setae; claws short and simple. Mesotrochanter elongate/oval with a few thin setae on inner edge; mesofemur with 3 spines in basal half, basal two close together (Fig. 28); mesotarsus more elongate than protarsus, individual segments about half as broad. Metatrochanter tip bluntly pointed (Fig. 29); metafemur relatively stout, lacking spines; metatibia narrow, weakly curved, widening towards apex; metatarsus elongate, segment 1 longest, segment 5 longer than segment 4, segments 1 and 2 in combination about as long as others; claws weak.

Male

Sexes externally similar. Median lobe of aedeagus slightly variable in width along shaft, narrowing to tip which is rounded and slightly twisted; paramere broad, apical segment with relatively short, narrow, apical lobe well separated from rest of segment. Figs 25-27.



Figs 37-42. *Nirripiri bulbos*: 37, lateral view of central lobe of aedeagus; 38, ditto dorsal view; 39, paramere; 40, mesotrochanter and mesofemur; 41 metatrochanter and metafemur; 42, dorsal view. Scale bar represents 1mm (habitus only).

Etymology

Named after the pastoral well in which it was found.

Remarks

A small species recognised by the three spines on the mesofemur, lack of pronotal plicae and with sutural punctures and pointed metatrochanters. The hind wings are the most reduced – to tiny flaps – yet seen in *Tjirtudessus*.

***Nirripiri* Watts and Humphreys
(Hydroporinae: Hydroporini).**

***Nirripiri arachnoides* sp. nov.**
FIGS 31-36

Holotype

m. 'BES 9367, Byro Station, Yalcallia Well, 25° 54' 39" S 115° 53' 03" E, 10/6/02, W. F. Humphreys & R. Leys', WAM 34201. Slide mounted.

Paratypes

21; 11, as for holotype, 5 WAM 34202 - 34206, 6 SAMA; 10 as for holotype except 'BES 9368', 4 WAM 34207 - 34210, 6 SAMA.

Description (number examined, 22)

Habitus. Length 2.2 – 2.3 mm; head and pronotum small compared with almost globular elytra, relatively flat, moderately constricted at junction of pronotum/elytra; uniformly light testaceous; hindwing vestigial, reduced to tiny flap.

Head. Small, about a third width of elytra; smooth, moderately strong reticulation with small even meshes, a few scattered small punctures; sides parallel, weakly indented at eye remnant; eye remnant reduced to short suture. Antenna relatively thin, segments 1 and 2 cylindrical, segments 3 to 10 of roughly similar shape but segments 5 to 7 somewhat longer than others, segment 11 thin a little longer than segment 10, each segment with some very small setae on inside apically. Maxillary palpus elongate, segment 4 1.3x as long as segment 3.

Pronotum. Much narrower than elytra;

anteriolateral angles projecting strongly forward; sides sinuate, converging towards rear; posteriolateral angles obtuse; a few scattered minute punctures; long setae laterally, denser towards front; moderately strong reticulation.

Elytra. Not fused, tightly closed, lacking inner ridges; widely oval, widest near shoulders, smooth; covered with fine reticulation; a few scattered small punctures; a few additional larger punctures with long setae, more frequent towards apex, near scutellum and sides. Epipleuron well marked, broad in anterior third, then gradually narrowing to near apex.

Ventral surface. Prosternal process strongly narrowed between coxae, not reaching mesothorax, apical half spatulate, strongly arched in lateral view with highest point (viewed ventrally) between coxae. Mesocoxae in contact in midline. Metathorax very sharply triangularly projecting forward in midline; wings short, very narrow; widely rounded in midline behind. Metacoxal plates large, metacoxal lines absent; virtually impunctate; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct in inner two-thirds absent laterally, ventrites 3 to 5 mobile, virtually impunctate except for a few long central setae or bunch of long setae

Legs. Protibia long, narrow, widest past middle where it is about 1.5 x its basal width; protarsus small, weakly expanded, segment 1 broadly triangular, segment 2 about one half length of segment 1, segment 3 longer than segment 1, very deeply bifid, segment 4 very small and hidden within lobes of segment 3, segment 5 cylindrical, about as long as segment 3, segments 1 to 3 with dense covering of adhesive setae; claws short and simple. Mesotrochanter elongate with a few fine setae at apex; mesofemur with row of 5 long spines along hind edge in basal half; mesotibia thin, slightly angular, front edge uneven with long stout setae; mesotarsus more elongate than protarsus (Fig. 34). Metatrochanter roughly oval; metafemur elongate, lacking spines (Fig. 35); metatibia straight, approximately the same width throughout; metatarsus elongate, segment 1 longest, segment 4 shortest; in combination segments 1 and 2 about same length as others, segments 2 to 5 without spines other than at apex; claws weak.

Male

Little external difference between sexes. Central lobe of aedeagus relatively broad, widening slightly towards front. Parameres of average width, tips with two long setae. Figs 31-33.

Etymology

Greek. 'Arachne' spider. An allusion to its spider-like shape.

Remarks

A very distinctive species readily recognised by its pronounced spider-like shape - small head and pronotum together with large broad body and long thin legs - as well as the five long spines on the mesofemur, angular very spinose mesotibia, unusually thin tarsi, impunctate ventrites, wide epipleura and flanged elytra.

Nirripirti bulbosus sp. nov.

FIGS 37-42.

Holotype

m. 'BES 9324, Moorarie Station, bore nr. calcrete quarry, site 419, 25° 52' 26" S 117° 27' 09" E., 8/6/02, W. F. Humphreys & R. Leys', WAM 34211. Slide mounted.

Paratypes

11; 3, as for holotype, SAMA; 8 as for holotype except 'BES 9325', 5 SAMA, 3 WAM 34212 34214.

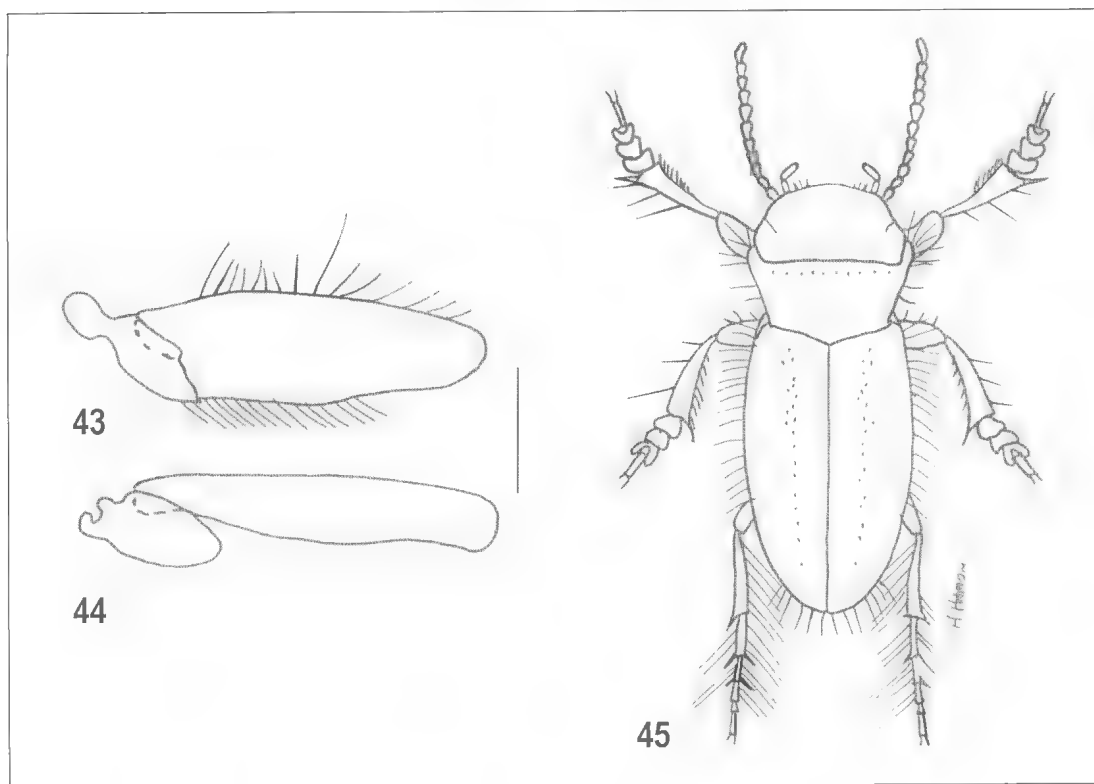
Description (number examined, 12)

Habitus. Length 2.1 - 2.5 mm; narrowly boat-shaped, relatively flat, slightly depressed in sutural region, base of pronotum not constricted; uniformly light testaceous; rather weakly sclerotized; hindwing vestigial, reduced to tiny flap.

Head. Relatively small, much narrower than elytra; smooth, moderately strong reticulation with small even meshes, a few scattered small punctures; sides parallel; eye remnant reduced to short suture line. Antenna relatively thick, segments 1 and 2 cylindrical, about same length, segment 3 about same length but half width of segment 2, segment 4 same shape but a little shorter than segment 3, apex of segment 6 moderately expanded on inside, segments 7 and 8 expanded, almost globular, segments 9 and 10 narrower, segment 11 about 1.3x as long as and thinner than segment 10, each segment with some very small setae on inside apically. Maxillary palpus elongate, segment 4 a little longer than segment 3.

Pronotum. Narrower than elytra; anteriolateral angles projecting forward; sides almost parallel, posteriolateral angles right angles; a few scattered minute punctures and a few larger ones along front edge; moderately strongly reticulate.

Elytra. Not fused, tightly locked, lacking inner ridges; elongate, parallel sided, smooth; covered with relatively strong, regular reticulation; a few scattered small punctures; a few additional larger punctures with long setae, more frequent towards apex and sides. Epipleuron not differentiated, that portion of elytron visible ventrally broad, of even width along most of elytron except close to apex.



Figs 43-45. *Nirripiriti byroensis*: 43, mesotrochanter and mesofemur; 44 metatrochanter and metafemur; 45, dorsal view. Scale bar represents 1mm (habitus only).

Ventral surface. Prosternal process strongly narrowed between coxae, not reaching mesothorax, apical half spatulate, strongly arched in lateral view with highest point (viewed ventrally) between coxae. Mesocoxae in contact in midline. Metathorax weakly projecting forward in midline; wings very narrow; widely triangular behind, apex blunt. Metacoxal plates large; metacoxal lines absent; virtually impunctate, evenly covered with moderately strong reticulation; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct in inner half, absent laterally, ventrites 3 to 5 mobile, virtually impunctate except for a few long central setae or bunch of long setae.

Legs. Protibia narrow, widest past middle where it is about twice its basal width; protarsus weakly expanded, segment 1 broadly triangular, segment 2 about one half length of segment 1, segment 3 as long as segment 1, deeply bifid, segment 4 very small and hidden within lobes of segment 3, segment 5 stout, cylindrical, longer than segment 3, segments 1 to 3 with dense covering of adhesive setae; claws short and simple. Mesotrochanter elongate with a few fine setae at apex; mesofemur with row of 4 to 5

spines along hind edge in basal half, basal two close together, edge slightly indented between spines (Fig. 40); mesotarsus more elongate than protarsus. Metatrochanter relatively large, apex weakly pointed (Fig. 41); metafemur elongate, lacking spines; metatibia curved, approximately the same width throughout; metatarsus elongate, segment 1 longest, segment 4 shortest; in combination segments 1 and 2 shorter than others, segments 2 to 5 without spines other than at apex; claws weak

Male

Antenna with segments 6 to 8 more strongly expanded than the others and the ventral surface of segments 7 and 8 with a transverse groove at their bases. Tarsi similar in males and females. Central lobe of aedeagus narrow, apical quarter thin, tip rounded. Paramere relatively narrow, inner edge crenulated in basal half, tip with one long seta. Figs 37-39.

Etymology

Latin. 'Bulbus' - swollen. A reference to its swollen antennae.

Remarks

A moderate sized, boat-shaped species with wrap-around elytral epipleurae and antennae with distinctive, swollen, mid-segments in both sexes but more pronounced in the males.

Nirripiri byroensis sp. nov.

FIGS 43-45

Holotype

f. 'BES 9365, Byro Station, Yalcallia Well, 25° 54' 39" S 115° 53' 03" E, 10/6/02, W. F. Humphreys & R. Leys', WAM 34215. In spirit.

Paratype

1; as for holotype except BES 9366, SAMA.

Description (number examined, 2)

Habitus. Length 3.9 – 4.1 mm; elongate, relatively flat, slightly depressed in sutural region, moderately constricted at junction of pronotum/elytra; uniformly light testaceous; hindwing vestigial, reduced to tiny flap.

Head. Large, slightly narrower than elytra; smooth, moderately strong reticulation with small even meshes, moderately covered with scattered small punctures; sides sloping outwards backwards from antennal bases, then inwards to base; eye remnant reduced to short suture. Antenna moderately thin, segments 1 and 2 cylindrical, about same length, segments 3 and 4 half width and shorter than segment 2, segment 5 bit longer than segment 4, segments 6 to 10 larger, subequal, segment 11 a little longer than segment 10, each segment with some very small setae on inside apically. Maxillary palpus elongate, segment 4 a little longer than segment 3.

Pronotum. Slightly narrower than elytra; anteriolateral angles projecting strongly forward; sides weakly sinuate, converging towards rear, posteriolateral angles obtuse; a few scattered minute punctures and some stronger ones along front edge; reticulation relatively weak.

Elytra. Not fused, tightly closed, lacking inner ridges; elongate, sides almost parallel; smooth; covered with weak fine reticulation; sparsely covered with small punctures; a few additional larger punctures with long setae, more frequent towards apex and sides. Epipleuron moderately differentiated, broad in anterior quarter, then rapidly narrowing to middle, virtually absent along rest of elytron.

Ventral surface. Prosternal process very strongly narrowed between coxae, not reaching mesothorax, apical half spatulate, sharply pointed, strongly arched in lateral view with highest point (viewed ventrally) between coxae. Mesocoxae in contact in

midline. Metathorax sharply triangularly projecting forward in midline; wings relatively broad but short; moderately rounded in midline behind. Metacoxal plates relatively narrow; metacoxal lines obsolete, virtually impunctate, moderately reticulate; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct in inner half, indistinct laterally, ventrites 3 to 5 mobile, virtually impunctate except for scattered shallow punctures; each ventrite with a few long central setae or bunch of long setae; hind edge of ventrite 2 slightly sinuate.

Legs. Protibia relatively narrow, relatively even width, about 3x its basal width; protarsus strongly expanded, segment 1 broad, wider than long, lobes slightly asymmetrical, segment 2 about one half length of segment 1, segment 3 as long as segment 1 but narrower, deeply bifid, segment 4 very small and hidden within lobes of segment 3, segment 5 stout, cylindrical, longer than segment 3, segments 1 to 3 with dense covering of adhesive setae; claws short and simple. Mesotrochanter elongate, laterally compressed, with a few fine setae at apex; mesofemur with row of about 20 short spines along hind edge in basal half (Fig. 43); mesotarsus similar shape but smaller than protarsus. Metatrochanter relatively large, elongate/oval, rounded at apex (Fig. 44); metafemur elongate, lacking spines; metatibia weakly curved, slightly expanded towards apex; metatarsus elongate, segment 1 longest, segment 4 shortest; in combination segments 1 and 2 a little longer than others, segments 2 to 5 without spines other than at apex; claws weak.

Male

Unknown.

Etymology

Named after the pastoral station on which it was found.

Remarks

A large, well-chitinized species with thin tibiae but greatly expanded pro and mesotarsi, particularly the basal segments. The expansions are asymmetrical.

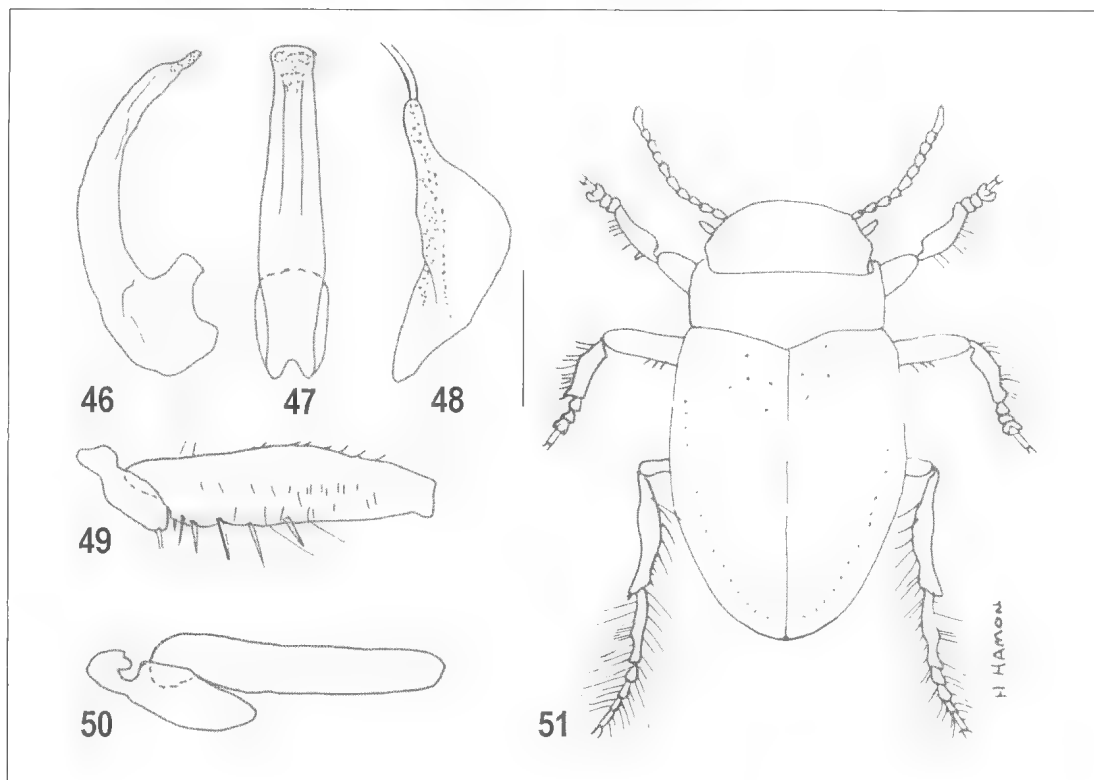
Although only two female specimens are known the almost straight, relatively even width of the metatibiae place it in the Hydroporini. DNA sequencing places it in a relatively isolated position within *Nirripiri* (Remko Leys pers com)

Nirripiri copidotibiae sp. nov.

FIGS 46-51

Holotype

m. 'BES 9335, Innouendy Station, mineral expl. bore, site 431, 25° 49' 19" S 116° 11' 29" E, 9/6/02,



Figs 46-51. *Nirripiri copidotibiae*: 46, lateral view of central lobe of aedeagus; 47, ditto dorsal view; 48, paramere; 49, mesotrochanter and mesofemur; 50, metatrochanter and metafemur; 51, dorsal view. Scale bar represents 1mm (habitus only).

W. F. Humphreys & R. Leys', WAM 34216. Slide mounted.

Paratype

1; m. ditto except BES 8808, 11/4/03, SAMA

Description (number examined, 2)

Habitus. Length 3.2 mm; elongate, relatively flat, slightly depressed in sutural region, not constricted at junction of pronotum/elytra but base of pronotum narrower than elytra; uniformly light testaceous; hindwing vestigial, reduced to tiny flap.

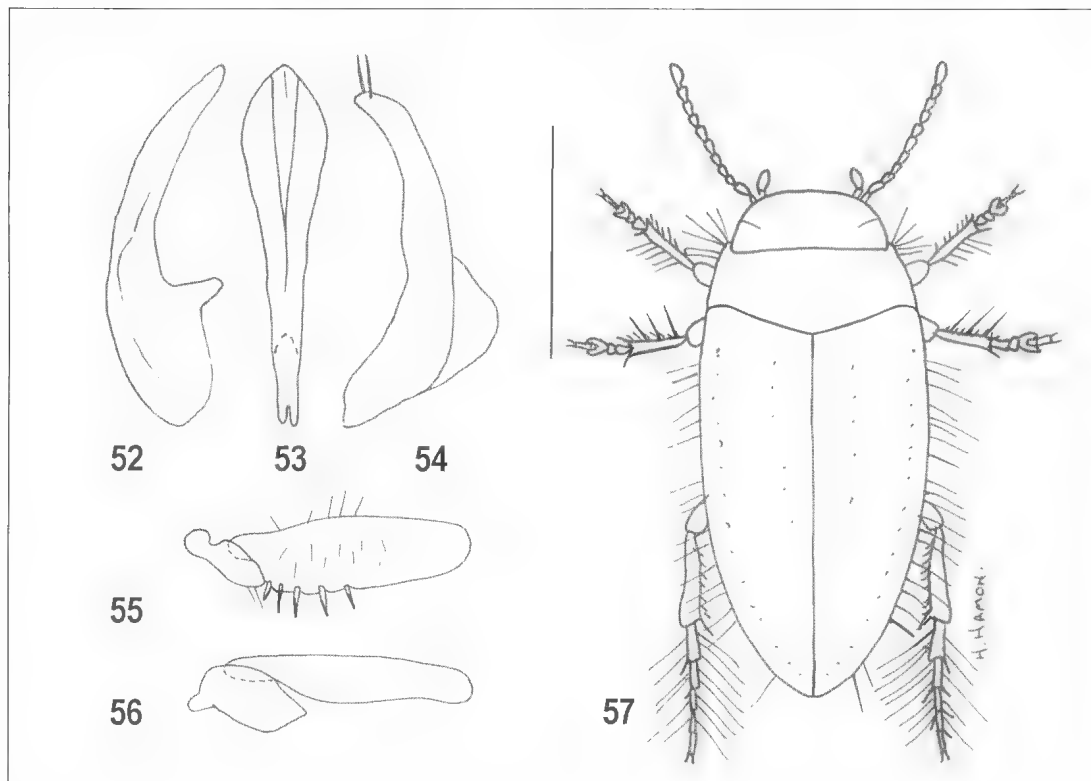
Head. Relatively broad, a little narrower than elytra; smooth, moderately strong reticulation with small even meshes, a few scattered small punctures; sides parallel; eye remnant reduced to short suture. Antenna relatively thin except for expanded segments 6 and 7, segment 1 cylindrical, segment 2 about same length, a little constricted basally, segments 3 and 4 half width and length of segment 2, segments 5 to 7 moderately expanded, segments 8 to 10 thinner, subequal, segment 11 about as long as segment 10, a little narrower, each

segment with some very small setae on inside apically. Maxillary palpus elongate, segment 4 a little longer than segment 5.

Pronotum. Narrower than elytra; anteriolateral angles projecting strongly forward; sides subparallel, posteriolateral angles obtuse; a few scattered minute punctures and some larger ones along front edge; reticulation moderately strong.

Elytra. Properly not fused, lacking inner ridges; elongate, nearly parallel sided, smooth; covered with moderately strong fine reticulation; a few scattered small punctures, a few additional larger punctures with long setae, more frequent towards apex and sides. Epipleuron moderately distinct, broad at base rapidly narrowing in anterior quarter, virtually absent along rest of elytron.

Ventral surface. Prosternal process strongly narrowed between coxae, not reaching mesothorax, apical half spatulate, apex pointed, very strongly arched in lateral view with highest point (viewed ventrally) between coxae. Mesocoxae in contact in midline. Metathorax projecting forward in midline; wings virtually absent; widely rounded in midline



Figs 52-57. *Nirripiri dingbatensis*: 52, lateral view of central lobe of aedeagus; 53, ditto dorsal view; 54, paramere; 55, mesotrochanter and mesofemur; 56, metatrochanter and metafemur; 57, dorsal view. Scale bar represents 1mm (habitus only).

behind. Metacoxal plates large, metacoxal lines short, indistinct, area between them and forward onto mesosternum depressed forming a large distinct midline groove; virtually impunctate, moderately reticulate; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct in inner two-thirds, absent laterally, ventrites 3 to 5 mobile, virtually impunctate except for a few long central setae or bunch of long setae.

Legs. Protibia relatively broad, widest in middle where it is about 5x its basal width, laterally compressed, almost blade-like; profemur with distinct, thin, dorsal portion near apex covering base of protibia; protarsus moderately expanded, segment 1 broadly rectangular, segment 2 about one half length of segment 1, segment 3 as long as segment 1, deeply bifid, segment 4 very small and hidden within lobes of segment 3, segment 5 stout, laterally compressed, about as long as segment 3, segments 1 to 3 with dense covering of adhesive setae; claws short and simple. Mesotrochanter elongate, laterally compressed with a few fine setae at apex; mesofemur with row of 6 strong

spines along hind edge in basal half (Fig. 49); mesotibia with large blade-like structure on ventral side near apex; basal segment of mesotarsus strongly expanded, other segments a little more elongate than protarsus. Metatrochanter relatively large, basal two thirds narrow, parallel sided, apical portion narrowing to blunt point, deflexed dorsally (Fig. 50); metafemur elongate, lacking spines; metatibia relatively broad, weakly curved, approximately the same width throughout except much narrower near base; metatarsus relatively stout, basal segment very long, nearly as long as length of other segments combined, with distinctive comb of 4 to 5 spines on outside, segments 2 to 5 short, about same length, segments 2 and 3 much wider than others, all segments with very strong spines; claws weak.

Male

Female unknown. Central lobe of aedeagus relatively broad, slightly wider at tip. Paramere relatively broad, tip with two long setae. Figs 46-48.

Etymology

Latin. 'Copsis' – knife. In reference to the sharp raised ridge on the protibia.

Remarks

A medium sized species immediately recognised by the highly modified legs. The pro and mesotibiae are enlarged and angular, particularly the mesotibiae, with blade-like extensions on the inside. The metatarsi have a greatly elongate first segment which has the spines which are usually found evenly spaced along the outside edge grouped tightly together near the middle. Another unique character is the distinct midline groove on the ventral surface of the thorax. Although only one male is known it is unlikely that all of these distinctive characteristics are restricted to males.

Nirripirti dingbatensis sp. nov.
FIGS 52-57

Holotype

m. 'BES 9347, Innouendy Station, Dingbat Well, 25° 52' 32" S 115° 53' 43" E, 10/6/02, W. F. Humphreys & R. Leys', WAM 34217. Slide mounted.

Paratypes

3; 1, as for holotype, SAMA, 2, as for holotype except 'BES 9346', SAMA.

Description (number examined, 4)

Habitus. Length 2.0 – 2.2 mm; elongate, relatively flat, not constricted at junction of pronotum/elytra; uniformly light testaceous; hindwing vestigial, reduced to tiny flap.

Head. Relatively small, much narrower than elytra; smooth, rather weak reticulation with small even meshes, a few scattered small punctures; sides parallel; eye remnant reduced to short suture. Antenna moderately thick, segments 1 and 2 cylindrical, segments 3 and 4 half width and length of segment 2, segment 5 bit longer than segment 4, segments 6 to 10 larger, subequal, segment 11 1.5x length of segment 10, each segment with some very small setae on inside apically. Maxillary palpus elongate, segment 4 a little longer than segments 2 and 3 combined.

Pronotum. Narrower than elytra; anteriolateral angles projecting forward; sides diverging towards the rear, posteriolateral angles right angles; a few scattered minute punctures and some larger ones along front margin; long setae at sides particularly towards front; moderately strongly reticulate.

Elytra. Not fused, tightly locked, lacking inner ridges; elongate, widest just behind middle; smooth;

covered with moderately strong fine reticulation; evenly but sparsely covered with small punctures, a few slightly larger punctures with long setae, more frequent towards apex and sides. Epipleuron moderately differentiated, broad in anterior fifth, virtually absent along rest of elytron.

Ventral surface. Prosternal process strongly narrowed between coxae, reaching mesothorax, apical half oval, strongly pointed behind, weakly arched in lateral view with highest point (viewed ventrally) between coxae. Mesocoxae not in contact in midline. Metathorax strongly projecting forward in midline; wings very short or absent; broadly rounded in midline behind. Metacoxal plates large, metacoxal lines weak, well separated, weakly diverging in front quarter, reaching to half way to mesosternum; sparsely covered with small punctures, moderately reticulate; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct, ventrites 3-5 mobile, strongly reticulate with scattered small punctures and a few long central setae or bunch of long setae.

Legs. Protibia narrow, widest near apex where it is about twice its basal width; protarsus weakly expanded, segment 1 broadly triangular, segment 2 a little smaller, segment 3 as long as segment 1, deeply bifid, segment 4 very small and hidden within lobes of segment 3, segment 5 stout, cylindrical, longer than segment 3, segments 1 to 3 with dense covering of adhesive setae; claws short and simple. Mesotrochanter elongate with a few fine setae at apex; mesofemur with row of 4 to 5 spines along hind edge in basal half (Fig. 55); mesotarsus a little more elongate than protarsus. Metatrochanter with apex weakly pointed, tip close to metafemur (Fig. 56); metafemur relatively stout, lacking spines; metatibia weakly curved, weakly expanded towards apex; metatarsus elongate, segment 1 longest, segment 4 shortest, in combination segments 1 and 2 shorter than others, segments 2 to 5 without spines other than at apex, segments 2 to 4 weakly hour-glass shaped; claws weak.

Male

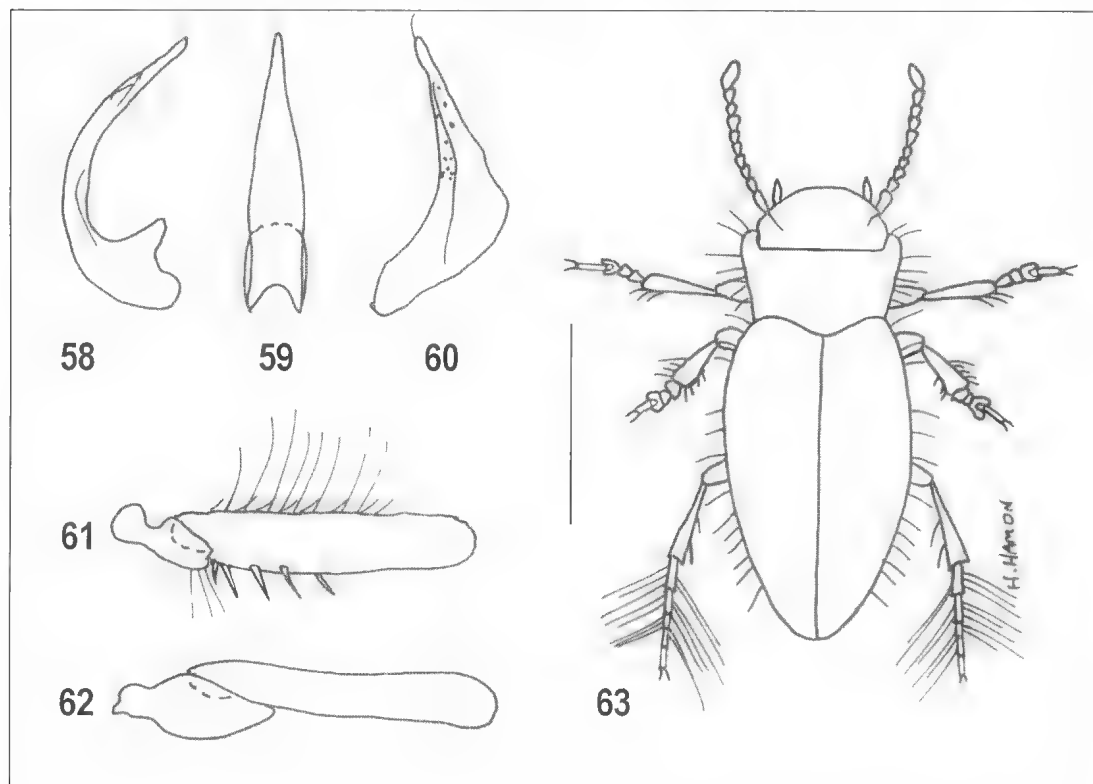
Antenna and protarsi slightly more expanded than in female. Central lobe of aedeagus broad, widening towards apex; paramere relatively narrow, tip with two long setae. Figs 52-54.

Etymology

Named after the well in which it was found.

Remarks

A medium sized species with weakly expanded tarsi and strongly pointed but weakly arched prosternal process. In morphology close to *N.*



Figs 58-63. *Nirripiri eurypleuron*: 58, lateral view of central lobe of aedeagus; 59, ditto dorsal view; 60, paramere; 61, mesotrochanter and mesofemur; 62, metatrochanter and metafemur; 63, dorsal view. Scale bar represents 1mm (habitus only).

innouendyensis and *N. skaphites* but with different prosternal process, different metatrochanters, thinner antennae and broad aedeagus.

Nirripiri eurypleuron sp. nov.

FIGS 58-63

Holotype

m. 'BES 9385, Moorarie Station, Wogartha Well, 25° 57' 58" S 117° 35' 28" E, 12/6/02, W. F. Humphreys & R. Leys', WAM 34218. Slide mounted.

Paratype

m. ditto except BES 8856, 16/4/03, SAMA.

Description (number examined, 2)

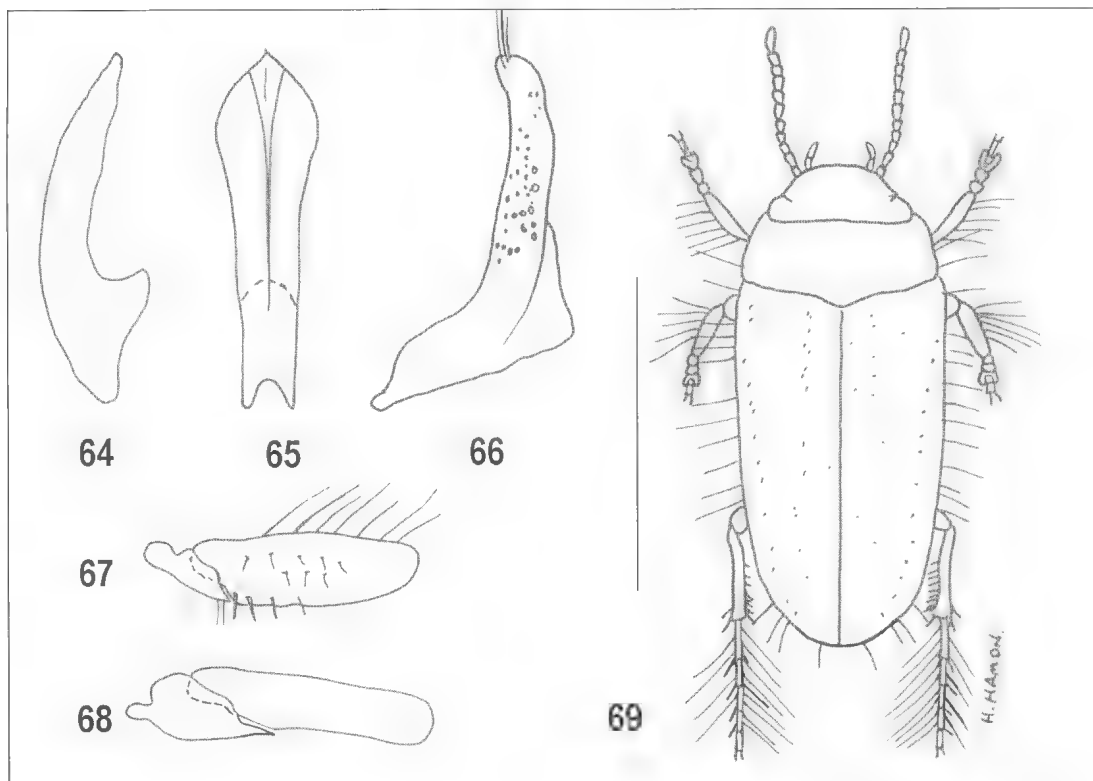
Habitus. Length 2.3 mm; narrowly elongate, relatively flat, slightly depressed in sutural region, pronotum much narrower than elytra, not constricted at base; uniformly light testaceous; hindwing vestigial, reduced to tiny flap.

Head. Relatively small, much narrower than elytra;

smooth, moderately strong reticulation with small even meshes, a few scattered small punctures; sides weakly indented at position of eye remnants; eye remnant reduced to very short suture. Antenna relatively stout, segment 1 cylindrical, segment 2 about same length, more oval, segment 3 half width and shorter than segment 2, segments 4 to 6 subequal in length becoming progressively slightly wider, segments 6 to 10 subequal, segment 11 about twice length of segment 10, each segment with some very small setae on inside apically. Maxillary palpus elongate, segment 4 about twice as long as segment 5.

Pronotum. Narrower than elytra; anteriolateral angles projecting strongly forward; sides parallel, posteriolateral angles square, overlapping base of elytra; a few scattered minute punctures and a few relatively large punctures along front edge; strongly reticulate.

Elytra. Possibly fused, lacking inner ridges; strongly elongate, sides parallel, smooth; covered with strong reticulation; a few scattered small punctures, a few additional larger punctures with long setae, more frequent towards apex and sides.



Figs 64-69. *Nirripiri innouendyensis*: 64, lateral view of central lobe of aedeagus; 65, ditto dorsal view; 66, paramere; 67, mesotrochanter and mesofemur; 68, metatrochanter and metafemur; 69, dorsal view. Scale bar represents 1mm (habitus only).

Epipleuron not differentiated, that portion of elytron visible ventrally very broad, broadest at junction of ventrites 2 and 3.

Ventral surface. Prosternal process strongly narrowed between coxae, not reaching mesothorax, apical half parallel sided, apex sharply pointed, strongly arched in lateral view with highest point (viewed ventrally) between coxae. Mesocoxae in contact in midline. Metathorax projecting forward in midline; wings very narrow, short; moderately rounded in midline behind. Metacoxal plates relatively narrow, large, metacoxal lines absent; strongly reticulate, virtually impunctate; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct in inner two-thirds, absent laterally, ventrites 3 to 5 mobile; virtually impunctate except for a few long central setae or bunch of long setae.

Legs. Protibia narrow, widest near apex where it is about twice its basal width; protarsus weakly expanded, segment 2 about one half length of segment 1, segment 3 as long as segment 1, bifid, segment 4 very small and hidden within lobes of segment 3, segment 5 stout, cylindrical about twice

length of segment 3, segments 1 to 3 with dense covering of adhesive setae; claws short and simple. Mesotrochanter elongate with a few fine setae at apex; mesofemur with row of 5 spines along hind edge in basal half (Fig. 61); mesotarsus similar to protarsus. Metatrochanter with curved inner edge, apex bluntly pointed (Fig. 62); metafemur elongate, lacking spines; metatibia straight, approximately the same width throughout; metatarsus elongate, segment 1 longest, segment 4 shortest, in combination segments 1 and 2 about same length as others, segments 2 to 5 without spines other than at apex; claws weak.

Male

(Female unknown). Antenna and legs as above. Central lobe of aedeagus narrowing in apical third, tip bluntly pointed. Paramere rather narrow, tip with single seta. Figs 58-60.

Etymology

Greek. 'Eurypleuron' - wide ribbed. In reference to the broad epipleura in this species.

Remarks

Occurs in the same calcrete as *T. wogarthaensis* which apart from the generic differences is much smaller and has narrow elytral epipleurae. A number of species of *Nirripirti* are now known to have "wrap-around" elytra: *N. stegastos*, *N. skaphites*, *N. killaraensis* and *N. bulbous*. These can be separated by characters given in the key.

***Nirripirti innouendyensis* sp. nov.**

FIGS 64-69

Holotype

m. 'BES 9339, Innouendy Station, mineral expl. bore site, 431m., 25° 49' 19" S 116° 11' 29" E, 10/6/02, W. F. Humphreys & R. Leys' WAM 34219. Slide mounted.

Paratypes

5; 1, as for holotype, WAM 34220; 1, as for holotype except, 'BES 9334', SAMA; 1, as for holotype except 'BES 9339', SAMA; 1, as for holotype except 'BES 9343, 10/6/03', SAMA; 1, as for holotype except 'BES 9342, 10/6/02', SAMA.

Description (number examined, 5)

Habitus. Length 1.8 – 2.1 mm; elongate, relatively flat, not constricted at junction of pronotum/elytra; uniformly light testaceous; hindwing vestigial, reduced to tiny flap.

Head Much narrower than elytra; smooth, moderate reticulation with small even meshes, a few scattered small punctures; sides parallel; eye remnant reduced to short suture. Antenna moderately thick, segment 1 cylindrical, segment 2 oval, about same length as segment 1, segments 3 and 4 half width and length of segment 2, segment 5 bit longer than segment 4, segments 6 to 10 larger, subequal, segment 11 2x length of segment 10, each segment with some very small setae on inside apically. Maxillary palpus elongate, segment 4 a little longer than segment 3.

Pronotum. Same width as elytra; anteriolateral angles projecting strongly forward; sides diverging slightly towards rear, posteriolateral angles right angles; a few scattered minute punctures and some larger ones along front edge; moderately reticulate.

Elytra. Not fused, but tightly closed, lacking inner ridges; broad, sides subparallel, smooth; covered with moderately fine reticulation; evenly but sparsely covered with small punctures; a few additional larger punctures with long setae, more frequent towards apex and sides. Epipleuron weakly differentiated, that portion of elytron visible ventrally broad in anterior fifth, virtually absent along rest of elytron.

Ventral surface. Prosternal process strongly narrowed between coxae, reaching mesothorax, apical half suboval, tip sharply pointed, in same plane as rest of body. Mesocoxae not in contact in midline. Metathorax strongly projecting forward in midline; wings very short; moderately rounded in midline behind. Metacoxal plates large, metacoxal lines weak, relatively wide, diverging slightly in anterior quarter, reaching to about half way to mesosternum; sparsely covered with scattered very small punctures; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct, ventrites 3 to 5 mobile, with scattered sparse small punctures and a few long central setae or bunch of long setae.

Legs. Protibia narrow, widest near apex where it is about three times its basal width; protarsus weakly expanded, segment 1 broadly triangular, segment 2 about one half length of segment 1, segment 3 as long as segment 1 deeply bifid, segment 4 very small, hidden within lobes of segment 3, segment 5 stout, cylindrical, longer than segment 3, segments 1 to 3 with dense covering of adhesive setae; claws short and simple. Mesotrochanter elongate with a few fine setae at apex; mesofemur with row of 4 evenly spaced spines along hind edge in basal half (Fig. 67); mesotarsus a little more elongate than protarsus. Metatrochanter with basal half broad, apical half elongate produced into long thin point (Fig. 68); metafemur elongate, lacking spines; metatibia curved, approximately same width throughout; metatarsus elongate, segment 1 longest, segment 4 shortest, in combination segments 1 and 2 about same length as others, segments 2 to 5 without spines other than at apex; claws weak.

Male

Little external difference between the sexes. Central lobe of aedeagus broad, widening towards apex. Paramere moderately broad, tip with two long setae. Figs 64-66.

Etymology

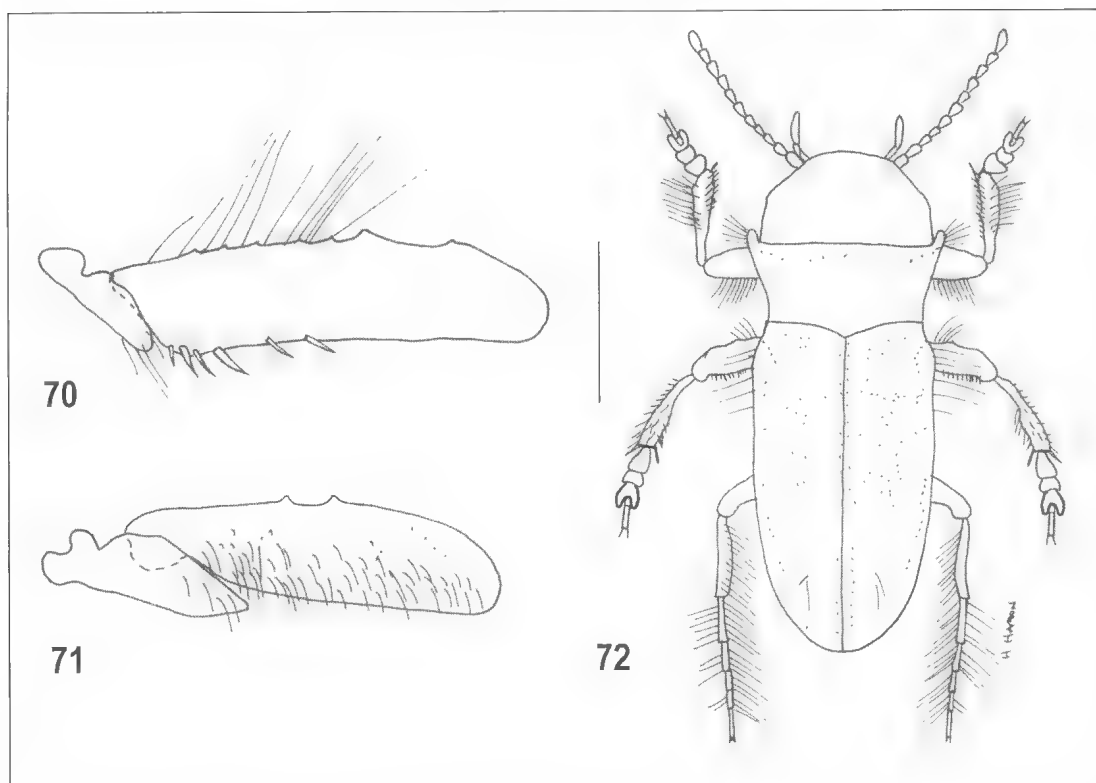
Named after the pastoral station on which it was found.

Remarks

A small, parallel sided, species readily recognised by the long, sharply pointed metatrochanters. One of the small number of *Nirripirti* with the prosternal process not arched in ventral view and with the tip reaching the metathorax.

***Nirripirti verrucosus* sp. nov.**

FIGS 70-72



Figs 70-72. *Nirripierti verrucosus*: 70, mesotrochanter and mesofemur; 71 metatrochanter and metafemur; 72, dorsal view. Scale bar represents 1mm (habitus only).

Holotype

f. 'BES 9386, Moorarie Station, Wogartha Well, 25° 57' 58" S 117° 35' 28" E, 12/6/02, W. F. Humphreys & R. Leys', WAM 34221. Slide mounted.

Description (number examined, 1)

Habitus. Length 3.2 mm; elongate, relatively flat, slightly depressed in sutural region, weakly constricted at junction of pronotum/elytra; uniformly light testaceous; hindwing vestigial, reduced to tiny flap.

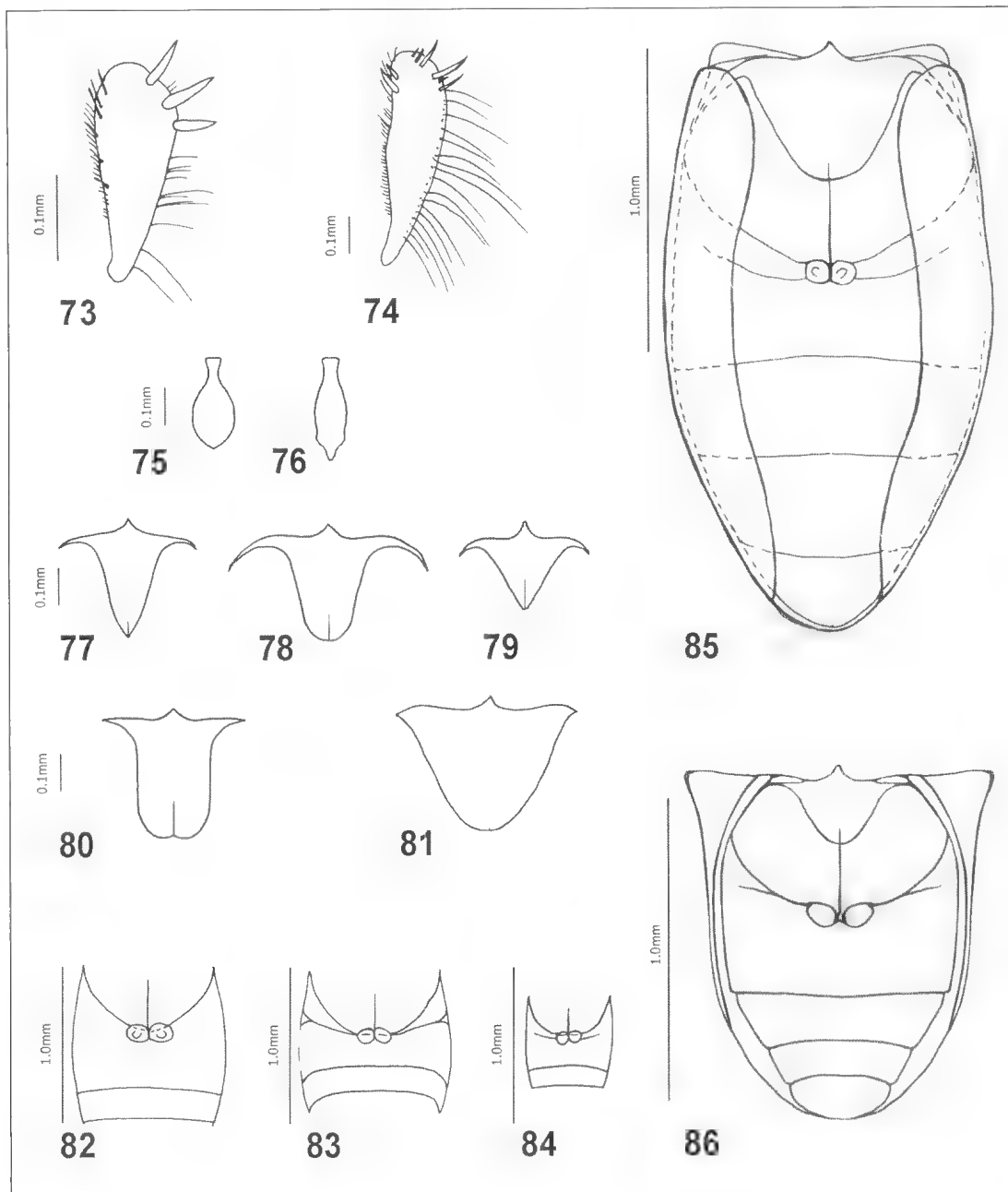
Head. Relatively large, a little narrower than elytra; smooth, moderate reticulation with very small even meshes, a few scattered small punctures; sides weakly concave behind eye remnant; eye remnant reduced to small suture. Antenna with segment 1 cylindrical, segment 2 more oval and about same length as segment 1, segment 3 same width but much narrower than segment 2, segments 4 to 8 progressively wider, segments 9 and 10 a little narrower than segment 8, segment 11 about 1.3x length of segment 10. Maxillary palpus elongate,

segment 4 longer than segment 5.

Pronotum. Slightly narrower than elytra, anteriolateral angles projecting strongly forward, sides narrowing towards rear, base weakly constricted, posteriolateral angles obtuse; a few scattered minute punctures and a few larger punctures near front edge; moderately reticulate with small meshes.

Elytra. Not fused, lacking inner ridges; elongate, almost parallel sided, smooth; covered with rather weak fine reticulation; a moderate number of scattered small shallow punctures, a few additional larger punctures with long setae, more frequent towards apex and sides. Epipleuron weakly differentiated, that portion visible ventrally broad in anterior quarter, then gradually narrowing to middle, virtually absent along rest of elytron.

Ventral surface. Prosternal process strongly narrowed between mesocoxae, not reaching mesothorax, apical half unusually elongate, apex bluntly pointed, strongly arched in lateral view with highest point (viewed ventrally) between coxae. Mesocoxae in contact in midline. Metathorax



Figs 73-86. Illustrations of characters used in the key to species. 73, protibia of *Bidessodes gutteridgei*. 74, ditto *Tjirtudessus padburyensis*. 75-76, Pronotal processes of *T. morgani*; 76 *T. bialveus*. 77-81, Mesosternal plates of; 77, *T. morgani*; 78, *T. pulpa*; 79, *T. bialveus*; 80, *Nirridessus fortisspina*; 81, *N. plutonicensis*. 82-84, ventrites 1-2 or 1-3 of; 82, *T. sweetwatersensis*; 83, *T. challaensis*; 84, *T. masonensis*. 85, Ventral view of abdomen showing wide "wrap-around" epipleura of *N. stegastos*. 86, ditto, *N. hamoni* showing flared shoulders and narrow epipleura.

TABLE 1. *The distribution of stylal species of dytiscids amongst discrete calcrete bodies in Australia. The separate palaeodrainage systems (Fig. 87) and the Indian Ocean and interior drainages are indicated. Species shown in bold are those treated in this paper. Species underlined occur in more than one calcrete.*

Calcrete	Palaeo valley	Species present
WESTERN DRAINAGES		
1, Cue	Murchison	<i>Tjirtudessus magnificus</i>
2, Austin Downs	Murchison	<i>Tjirtudessus cuensis</i>
3, Challa North	Murchison	<i>Tjirtudessus challaensis</i>
4, Killara	Murchison	<i>Nirripiri killaraensis</i>
5, Windimurra	Murchison	<i>Tjirtudessus</i> sp. 1
6, Moorarie Bin Bin	Murchison	<i>Boongurrus occidentalis</i> sp. nov.
7, Killara North	Murchison	<i>Boongurrus occidentalis</i> sp. nov.
8, Hillview	Murchison	<i>Tjirtudessus hillviewensis</i> sp. nov.
9, Mt Padbury	Murchison	<i>Tjirtudessus padburyensis</i> sp. nov.
10, Moorarie	Murchison	<i>Tjirtudessus wogarlhaensis</i> sp. nov.
11, Innouendy	Murchison	<i>Nirripiri copidotibiae</i> sp. nov.
12, Byro West	Murchison	<i>Nirripiri arachnoides</i> sp. nov.
13, Karalundi	Murchison	<i>Tjirtudessus karalundionis</i>
14, Three Rivers Station	Gascoyne	<i>Bidessodes gutteridgei</i>
15, Milgun Station	Gascoyne	<i>Nirripiri hamoni</i>
16, Landor Station	Gascoyne	
17, Bunawarra	Moore	<i>Tjirtudessus microocula</i> sp. nov.
INLAND DRAINAGES		
18, Paroo	Carey	<i>Tjirtudessus eberhardi</i>
19, Lake Violet	Carey	<i>Tjirtudessus wiltunaensis</i>
20, Uramurdah Lake	Carey	<i>Tjirtudessus hahni</i>
21, Hinkler Well	Carey	<i>Tjirtudessus hinkleri</i>
22, Mount Windarra	Carey	<i>Tjirtudessus windarraensis</i>
23, Melrose Station (Lake Darlot)	Carey	<i>Nirripiri darlotensis</i>
24, Depot Springs	Raeside	<i>Tjirtudessus frickayvelliensis</i>
25, Pinnacles Stn	Raeside	<i>Tjirtudessus pinnaclesensis</i>
26, Lake Mason	Raeside	<i>Tjirtudessus raesideensis</i>
27, Yuimmery	Raeside	<i>Tjirtudessus yuimmeryensis</i>
28, Jundee	Carnege	<i>Tjirtudessus jundeeensis</i>
29, Cunyur: Sweetwaters	Nabberu	<i>Tjirtudessus cunyurensis</i>
30, Cunyur: SBF	Nabberu	<i>Tjirtudessus bialveus</i>
31, Napperby	Ngalia Basin: N.T.	<i>Nirripiri macrocephalus</i>
32, Newhaven	Ngalia Basin: N.T.	<i>Nirripiri newhavenensis</i>
33, Central Mount Wedge	Ngalia Basin: N.T.	<i>Nirripiri wedgeensis</i>
33 calcretes 8 palaeodrainages		
		<i>Tjirtudessus cueensis</i>
		<i>Tjirtudessus highbellensis</i>
		<i>Tjirtudessus</i> sp. 2
		<i>Nirripiri bulbosus</i> sp. nov.
		<i>Nirripiri eurypleuron</i> sp. nov.
		<i>Nirripiri innouendyensis</i> sp. nov.
		<i>Nirripiri byroensis</i> sp. nov.
		<i>Nirripiri skaphites</i>
		<i>Bidessodes limstoneensis</i>
		<i>Nirripiri milgunensis</i>
		<i>Tjirtudessus</i> sp.
		<i>Tjirtudessus pulpa</i>
		<i>Tjirtudessus morgani</i>
		<i>Tjirtudessus</i> sp.
		<i>Tjirtudessus lapostae</i>
		<i>Nirripiri melroseensis</i>
		<i>Nirripiri hinzeae</i>
		<i>Nirripiri fortisspina</i>
		<i>Tjirtudessus masonensis</i>
		<i>Tjirtudessus silus</i>
		<i>Tjirtudessus macrotarsus</i>
		<i>Nirripiri napperbyensis</i>
		<i>Nirripiri pentameres</i>
		<i>Nirripiri</i> sp NT 9 and <i>Tjirtudessus</i> sp
		<i>Nirripiri</i> sp NT 7
		<i>Copelatus abditus</i>
		<i>Tjirtudessus sweetwatersensis</i>
		<i>Nirripiri</i> sp 8
		<i>Nirripiri</i> sp NT 9 and <i>Tjirtudessus</i> sp

projecting forward in midline; wings very narrow; moderately rounded in midline behind. Metacoxal plates large, metacoxal lines absent; virtually impunctate; closely adpressed to ventrite 1. Ventrites 1 and 2 fused, sutural lines distinct in inner two-thirds, absent laterally, ventrites 3 to 5 mobile, virtually impunctate except for a few long central setae or bunch of long setae.

Legs. Protibia distinctly club-shaped, widest towards apex where it is about four times its basal width; protarsus strongly expanded, segment 1 almost square, segment 2 about one half length of segment 1, segment 3 longer than segment 1, deeply bifid, segment 4 very small and hidden within lobes of segment 3, segment 5 stout, cylindrical, about as long as segment 3, segments 1 to 3 with dense covering of adhesive setae; claws short and simple. Mesotrochanter elongate with a few fine setae at apex; mesofemur with row of 5 short spines along hind edge in basal half (Fig. 70), the basal ones closer together, anterior edge uneven with a number of small protuberances, metatibia somewhat club-shaped; mesotarsus considerably more elongate than protarsus. Metatrochanter moderately large, basal half parallel sided apical half triangular, apex blunt, well separated from femur (Fig. 71); metafeur elongate, anterior edge uneven, lacking spines, ventral surface with short setae; metatibia relatively thick, curved, approximately the same width throughout; metatarsus elongate, segment 1 longest, segment 4 shortest; in combination segments 1 and 2 the same length as the others, segments 2 to 5 without spines other than at apex; claws weak.

Male

Unknown.

Etymology

Latin. 'Verrucosus' – full of warts. In reference to the warty edges of the mesofemurs.

Remarks

A large species recognised by the long thin club-shaped pro and mesotibia and the noticeable bumps on the front edge of the mesofemur. In general morphology resembles *N. hinzeae* and *N. darlotensis* but as well as the club-shaped tibiae and warty mesofemurs it has more elongate metatarsi, the prosternal process is much less deflexed and, uniquely among the Australian stygal Dytiscidae, the surface of the metafeur has a moderate covering of setae (Fig. 71).

Although known only from a single female specimen the relatively straight, even-width, metatibiae place it in the Hydroporini. Mitochondrial DNA places it in an isolated place within *Nirripiriti* (Remko Leys pers. com.).

Discussion

Distribution

Species described herein represent stygal beetles from two palaeodrainage systems, the Murchison and the Moore, both of which drain to the Indian Ocean (Fig. 87); in earlier papers in the series (Watts and Humphreys 1999, 2000, 2001, 2003; Balke et al 2004) we also recorded beetles from palaeodrainage systems which drained to the inland. It brings the number of described stygal Dytiscidae for Australia to 55 species in five genera (*Bidessodes*, *Copelatus*, *Kintinka*, *Nirripiriti* and *Tjirtudessus*). These are derived from 33 discrete groundwater calcrete deposits in eight palaeodrainages representing both coastal and interior drainages. In addition a number of other species that have not been formally described are recognised from larvae and females.

Of the 55 described stygobitic species of Dytiscidae from Australia (*ibid.*), *T. microocula* is the first in which the eyes are not entirely

TABLE 2. *Water quality data for several of the stygal water beetles.* Values are presented for the upper layer of water only through which the beetles need to pass to breathe. The vertical stratification for some deeper bores is shown in Figs 88–90.

Species	Temp. (°C)	pH	Specific conductance (mS cm ⁻¹)	Salinity (TDS mg L ⁻¹)	DO%	DO (mg L ⁻¹)	ORP (mV)	Depth (m)
<i>T. padburyensis</i>	19.81	7.94	2.49	1.28	53.5	4.82	448	0.1
<i>T. hillviewensis</i>	21.07	7.87	1.8	0.91	88.1	7.72	295	0.2
<i>N. dingbatensis</i>	21.54	7.9	15	8.68	57.3	4.77	351	0.3
<i>N. copidotibiae</i>	27.12	7.39	2.54	1.31	82.4	6.5	371	0.3
<i>N. innouendyensis</i>	27.12	7.39	2.54	1.31	82.4	6.53	71	0.3
<i>N. bulbosus</i>	25.17	8.53	2.6	1.34	93.8	7.64	346	0.3
<i>N. arachnoides</i>	19.87	8.1	4.88	2.6	72.9	6.51	228	0.1
<i>N. byroensis</i>	19.87	8.1	4.88	2.6	72.9	6.51	228	0.1
<i>B. occidentalis</i>	26.47	7.68	2.47	1.27	54.9	4.36	313	0.1

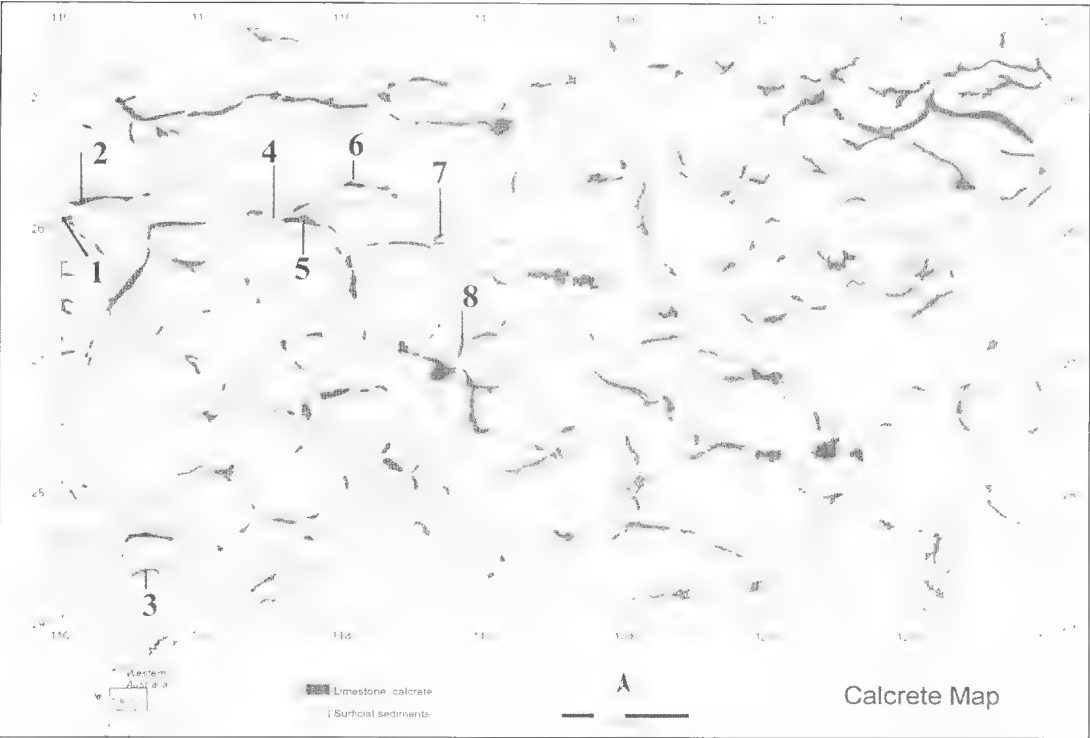


Fig. 87. The distribution of the species discussed in this paper in the groundwater calcrete aquifers of the Yilgarn area of Western Australia. The dark shading denotes groundwater calcrete bodies and the lighter shading the surficial sediments associated with the palaeodrainages incised into the Archaean basement. The calcrete bodies are referred to as 1: Byro; 2, Innouendy; 3, Bunnawarra; 4, Mt. Gould (the Wittenoom population of *B. occidentalis* sp. nov. is 400 km north of this site); 5, Moorarie; 6, Mt. Padbury; 7 Killara North; 8, Hillview. All sites are in the Murchison catchment except Bunnawarra which is in the Moore palaeodrainage. Map based on 1: 2,500,000 *Hydrogeological Map of Western Australia* 1989 compiled by D.P. Commander.

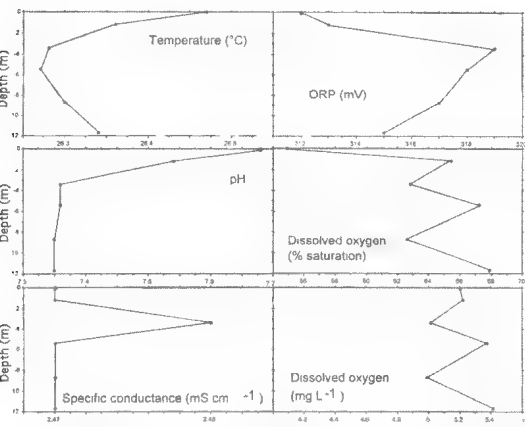


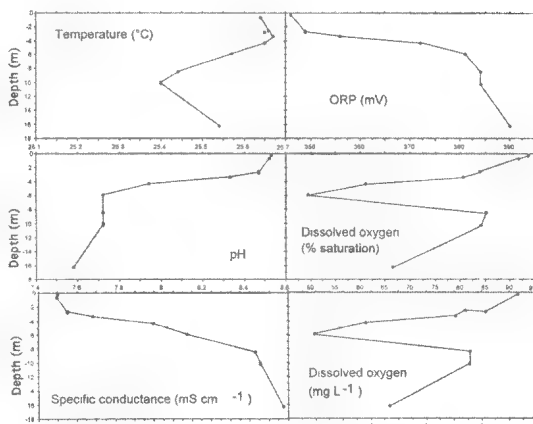
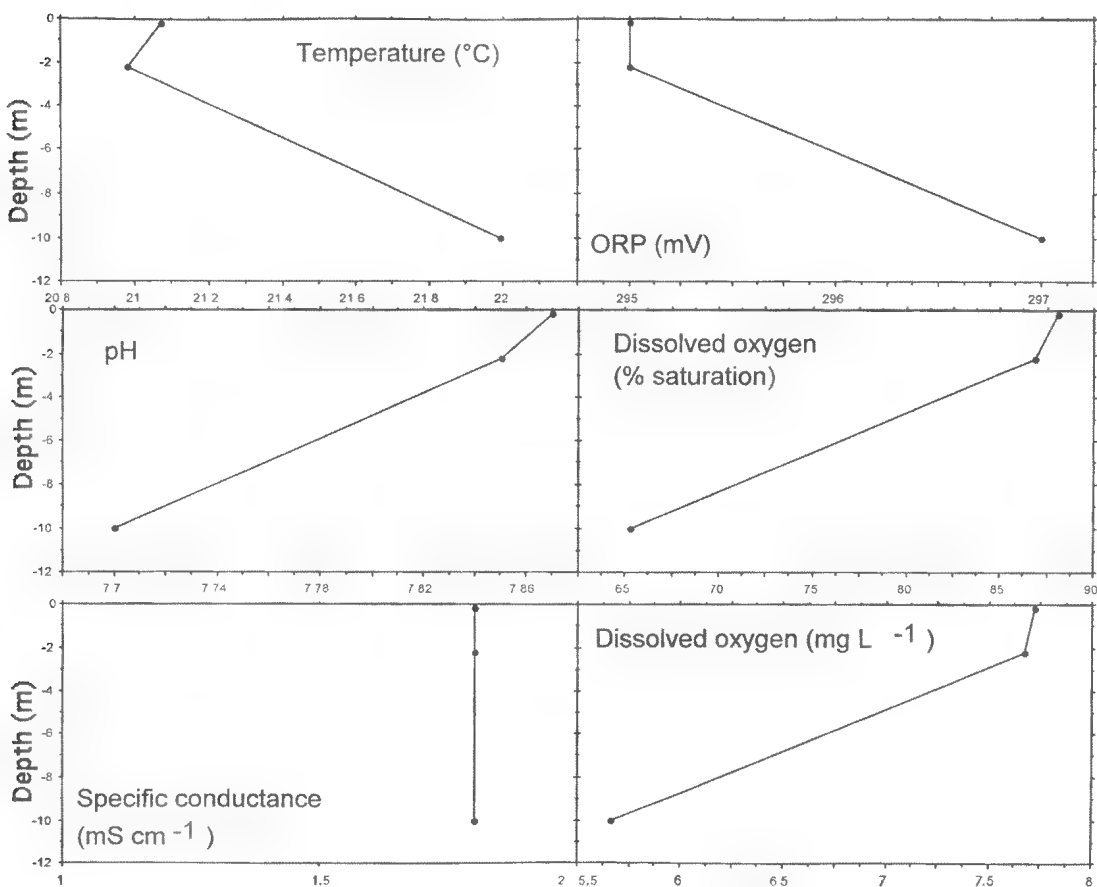
Fig. 88. Depth profiles of several physico-chemical parameters in the bore inhabited by *Boongurrus occidentalis* sp. nov. in an uncapped, never-used water bore in the Killara North calcrete.

reduced, being about one-fifth the size of those in epigeal species and seemingly lacking discrete ommatidia. Most interestingly, an undescribed sister species (determined from DNA) from the same calcrete also retains eye remnants to a similar degree suggesting that this lineage is of more recent evolution to subterranean life than the other stygal members of the genus.

Boongurrus occidentalis sp. nov. is the first clearly epigeal species to be found in deep groundwater in Australia. However, other epigeal species have been recorded from underground habitats: *Copelatus australis* (Clark) from hyporheic systems within river gravels in the Flinders Range, South Australia (Remko Leys, pers. com.) and *C. irregularis* Macleay from small pools of water in the furthest reaches of deep vertical caves in arid Cape Range, northwestern Australia (W.F.H. personal observation).

TABLE 3. Stygofauna recorded from the same calcrete bodies from which the Dytiscidae reported here were collected.

Calcrete	Associated stygal taxa
Bunnawarra	Amphipoda, Ostracoda, Harpacticoida, Cyclopaedia, Annelida
Badja	Oniscidea (Isopoda), crangonytoid and Ceinidae Amphipoda, Cyclopoida, Ostracoda
Killara north	Bathynellacea, crangonytoid and Ceinidae Amphipoda, Harpacticoida, Cyclopoida
Mt Padbury	Bathynellacea, crangonytoid and Ceinidae Amphipoda, Cyclopoida, Ostracoda
Mt Gould	Bathynellacea, Amphipoda
Innouendy	Microturbellara, crangonytoid Amphipoda, Cyclopoida, Ostracoda
Byro	Ostracoda
Moorarie	Amphipoda, Ostracoda, Cyclopoida
Belele	Ostracoda

Fig. 89. Depth profiles of several physico-chemical parameters in a capped bore inhabited by *Nirriparti bulbus* sp. nov. and *Boongurrus occidentalis* sp. nov.Fig. 90. Depth profiles of several physico-chemical parameters in Camel Well inhabited by *Tjirtudessus hillviewensis* sp. nov. in the Hillview calcrete.

Environment

Groundwater in the arid zone is sometimes markedly stratified in respect of salinity *inter alia* (Watts and Humphreys 2000). However, groundwater characteristics near the water table must be utilised by at least the larger species of stygal beetles, as they need to traverse it to reach free air to breathe. The physico-chemical characteristics of the superficial part of the groundwater at the sites of 9 of the 13 species described herein are given in Table 2. These waters are generally of rather low salinity for the Yilgarn (900–2600 mg L⁻¹ TDS) with the exception of the site for *N. dingbatensis* sp. nov. (Table 2). The latter site, while being part of the Murchison palaeovalley, which now contains the large episodic Murchison drainage, now lies in the separate small drainage of the Wooramel River and showed a much greater salinity (8680 mg L⁻¹ TDS).

Several sampling sites contained sufficiently deep water for profiling. Generally these showed little stratification and the values over which the variables ranged was small (Figs 88 and 90). Only the site occupied by *N. bulbosus* sp. nov. exhibited a marked salinity gradient (Fig. 89) and this was accompanied by large changes in pH, redox and oxygen level. In other stratified systems a pronounced nadir in oxygen levels associated with the halocline and the reduction in pH have been associated with a cascade of nitrogen species and sulphur bacteria (Humphreys 1999). The typically high nitrate and sulphate contents of the Yilgarn aquifers potentially could similarly support chemoautotrophic sulphur bacteria, providing a source of energy for the ecosystem

(Humphreys 2001), however, there is no indication from the ORP values that such is the case here and the changes in oxygen level may result from groundwater flow.

Associated fauna

The fauna associated with the stygal beetles is shown in Table 3 at a high taxonomic level. These are likely to represent substantial diversity and many short-range endemics, as has been found in some other taxa in calcretes containing stygal dytiscids where studies have been completed. For example, 31 species of copepods, including five new genera and 23 new species have been described for other calcretes in the Yilgarn (Karanovic 2003). Five new species of *Candonopsis* (Candoninae: Ostracoda) have been described from similar areas, all but one species restricted to a single calcrete area (Karanovic and Marmonier 2002). Finally, four new species of stygal Oniscidea (families Scyphacidae and Philosciidae) have been described from calcretes, three of the species from a single saline calcrete (Taiti and Humphreys 2001).

Acknowledgments

We greatly appreciate the support of Remko Leys in the field, Julianne Waldock in Perth, and the information and access provided by the managers of pastoral leases. The illustrations were very ably prepared by Howard Hamon. This work was partly supported by a grant from the Australian Biological Resources Study.

References

- BALKE, M., WATTS, C. H. S., COOPER, S. J. B., HUMPHREYS, W. F. & VOGLER, A. P. (2004) A highly modified stygobitic diving beetle of the genus *Copelatus* (Coleoptera, Dytiscidae): taxonomy and cladistic analysis based on mtDNA sequences. *Systematic Entomology* **29**: 59–67.
- COOPER, S. J. B., HINZEL, S., LEYS, R., WATTS, C. H. S. & HUMPHREYS, W. F. (2002). Islands under the desert: molecular systematics and evolutionary origins of stygobitic water beetles (Coleoptera: Dytiscidae) from central Western Australia. *Invertebrate Systematics* **16**: 589–598.
- HUMPHREYS, W. F. (1999). Physico-chemical profile and energy fixation in Bundera Sinkhole, an anchialine remiped habitat in northwestern Australia. *Journal of the Royal Society of Western Australia* **82**: 89–98.
- (2001). Groundwater calcrete aquifers in the Australian arid zone: the context to an unfolding plethora of stygal biodiversity. Pp 63–83 *In* 'Subterranean Biology in Australia 2000'. Eds. W. F. Humphreys and M. S. Harvey. *Records of the Western Australian Museum*, Supplement **64**.
- KARANOVIC, I. & MARMONIER, P. (2002). On the genus *Candonopsis* (Crustacea: Ostracoda: Candoninae) in Australia, with a key to the world recent species. *Annals of Limnology* **38**: 199–240.
- KARANOVIC, I. (2004). Subterranean copepods (Crustacea: Copepoda) from arid Western Australia. *Crustaceana Supplement* **3**: 1–366.
- LARSON, D. J. (1994). *Boongurrus rivulus*, a new genus and species of water beetle (Coleoptera, Dytiscidae, Bidessini) from northern Queensland, Australia. *Journal of the Australian Entomological Society* **33**: 217–221.
- LEYS, R., COOPER, S. J. B., WATTS, C. H. S., & HUMPHREYS, W. F. (2003). Evolution of subterranean diving beetles (Coleoptera, Dytiscidae, Hydroporini, Bidessini) in the arid zone of Australia. *Evolution* **57**: 2819–2834.
- TAITI, S. & HUMPHREYS, W. F. (2001). New aquatic Oniscidea (Crustacea, Isopoda) from groundwater calcretes of Western Australia. Pp.133–151. *In* 'Subterranean Biology in Australia 2000'. Eds. W. F. Humphreys and M. S. Harvey. *Records of the Western Australian Museum*, Supplement No. 64.

WATTS, C. H. S. & HUMPHREYS, W. F. (1999). Three new genera and five new species of Dytiscidae (Coleoptera) from underground waters in Australia. *Records of the South Australian Museum* **32**: 121-142.

& (2000). Six new species of *Nirridessus* and *Tjirtudessus* (Dytiscidae; Coleoptera) from underground waters in Australia. *Records of the South Australian Museum* **33**: 127-144.

& (2001). A new genus and six new species of Dytiscidae (Coleoptera) from underground waters in the Yilgarn palaeodrainage system of Western Australia. *Records of the South Australian Museum* **34**: 99-114.

& (2003). Twenty-five new Dytiscidae (Coleoptera) of the genera *Tjirtudessus* Watts & Humphreys, *Nirripiri* Watts & Humphreys and *Bidessodes* Regimbart, from underground waters in Australia. *Records of the South Australian Museum* **36**: 135-187.

REVISION OF AUSTRALIAN SCIRTES ILLIGER AND ORA CLARK (COLEOPTERA: SCIRTIDAE)

*By C. H. S. WATTS**

Summary

Watts, C. H. S. 2004. Revision of Australian Scirtes Illiger and Ora Clark (Coleoptera: Scirtidae). Trans. R. Soc. S. Aust. 128(2), 131-168, 30 November, 2004. The Australian members of the genera Scirtes Illiger and Ora Clark (Coleoptera: Scirtidae) are revised. Thirty three species are recognised: Scirtes helmsi Blackburn, S. exoletus Waterhouse, S. brisbanensis Pic and 30 new species: S. alastairi, S. albamaculatus, S. auritus, S. baroalba, S. beccus, S. calmi, S. crassiantennae, S. cygnus, S. emmae, S. interstinctus, S. kaytae, S. macroconcolor, S. microrotundus, S. musica, S. nalyerensis, S. nigerpalpus, S. orientalis, S. peniculus, S. podlussanyi, S. pygmaeus, S. pinjarraensis, S. ruforotundus, S. rivularis, S. spatula, S. storeyi, S. tindaleensis, S. triangulus, S. victoriaensis, Ora floccosus, O. improtectus, O. justafloccosus. The genus Ora is recorded from Australia for the first time. All species are described and the male genitalia illustrated. A key is provided to the species.

Key Words: Coleoptera, Scirtidae, Australia, taxonomy, morphology, distribution.

REVISION OF AUSTRALIAN *SCIRTES* ILLIGER AND *ORA* CLARK (COLEOPTERA: SCIRTIDAE)

by C. H. S. WATTS*

Summary

Watts, C.H.S. 2004. Revision of Australian *Scirtes* Illiger and *Ora* Clark (Coleoptera: Scirtidae). *Trans. R. Soc. S. Aust.* 128(2), 131-168, 30 November, 2004.

The Australian members of the genera *Scirtes* Illiger and *Ora* Clark (Coleoptera: Scirtidae) are revised. Thirty three species are recognised: *Scirtes helmsi* Blackburn, *S. exoletus* Waterhouse, *S. brisbanensis* Pic and 30 new species; *S. alastairi*, *S. albamaculatus*, *S. auritus*, *S. baroalba*, *S. beccus*, *S. calmi*, *S. crassiantennae*, *S. cygnus*, *S. emmae*, *S. interstinctus*, *S. kaytae*, *S. macroconcolor*, *S. microrotundus*, *S. musica*, *S. nalyerensis*, *S. nigerpalpus*, *S. orientalis*, *S. peniculus*, *S. podlussanyi*, *S. pygmaeus*, *S. pinjarraensis*, *S. ruforotundus*, *S. rivularis*, *S. spatula*, *S. storeyi*, *S. tindaleensis*, *S. triangulus*, *S. victoriaensis*, *Ora floccosus*, *O. improtectus*, *O. justafloccosus*. The genus *Ora* is recorded from Australia for the first time.

All species are described and the male genitalia illustrated. A key is provided to the species.

KEY WORDS: Coleoptera, Scirtidae, Australia, taxonomy, morphology, distribution.

Introduction

Australian Scirtidae (Marsh Beetles) are a common component of fresh water ecosystems. The larvae are detritus feeders living in shallow water near the edges of ponds, marshes and rivers, or in situations where they can readily reach the surface to breathe. Adults are terrestrial, sheltering in thick vegetation near water or feeding on nearby flowering shrubs. Very little is known about their natural history, in major part due to the inability to identify species, other than the tree-hole dwelling *Prionocyphon niger* Kitching & Allsopp (1987) from South-eastern Queensland extensively studied by Kitching (Kitching & Callaghan 1982).

Blackburn (1891), Lea (1919), and Carter (1935) described a number of species (under the rubric Helodidae) but it was not until Jack Armstrong began his work on the group in the early 1950's that much taxonomic attention was paid to the family. Unfortunately he completed and published only one paper in which he described 3 genera and 14 species (Armstrong 1953). When he stopped his taxonomic work he was close to the completion of manuscripts on the genera *Cyphon* and *Scirtes*; so close to completion, that specimens of these genera labelled as paratypes are scattered in a number of collections.

The generic boundaries and placements of the Australian Scirtidae require close examination (Hiroyuki Yoshitomi *pers. com.*). This problem is less critical in the genera *Ora* and *Scirtes*, which, although both probably polyphyletic, are well characterised by the possession of greatly enlarged hind femurs that are used for jumping, presumably as

a predator avoidance mechanism. The genus *Ora* has not previously been recorded from Australia but three species described here from Northern Australia appear to belong in the genus. The genus *Ora* is typically found in tropical rainforests in America, Africa and Asia (Yoshitomi *pers. com.*). The few Australian specimens known have all come from tropical areas close to if not in rainforest. The genus *Scirtes* occurs most commonly in tropical northern Australia where species are often collected at light but also in southern Australia with one species, *S. exoletus* Waterhouse, reaching northern Tasmania. This is in direct contrast to the situation in the remaining Australian Scirtid genera which have a more southern distribution and are commonest in Tasmania, in both number of species and in number of individuals.

Methods

For the identification of many species dissection and examination of the male genitalia is required. The female genitalia, although varying somewhat between the species examined, are more uniform and offer few taxonomic characters. For dried specimens, specimens were sexed by examination of the apex of the abdomen. In many females (approximately 80%) the ovipositor was at least partially visible. In a few species the tips of the male genitalia are also often visible. Specimens without extruded ovipositors were softened in an ultrasonic water bath for 30-45 minutes and the genital complex (see later) was teased, approaching dorsally, from the rest of the abdomen with a pair of fine forceps. The penis and tegmen were separated from the modified abdominal segments 8 and 9 and mounted on card in a drop of P.V.A. wood-working glue, which is transparent

* Division of Entomology, South Australian Museum.

when dry, or on a microscope slide in a polyvinyl alcohol based mountant. Drawings were made from camera lucida tracings. For a number of species only a handful, or fewer, of male specimens were available, often old and hence difficult to soften and dissect, which resulted in less than perfect material to work from. The male genitalia are complex and can vary enormously in structure between species. In these circumstances the preparations were often adequate to clearly indicate that a taxa was new but not good enough to allow a confident interpretation of fine structural detail. Thus I expect that in some cases my interpretations of the detail of the male genitalia may need to be modified when fresh material becomes available.

As well as the male genitalia, specimens of nearly all the small to medium sized species were also mounted on microscope slides.

Source of specimens

Specimens on which this revision was based were obtained from the following collections. AM, Australian Museum, Sydney; ANIC, Australian National Insect Collection, Canberra; QPIM, Queensland Department of Primary Industries, Mareeba; HUNG, Hungarian Natural History Museum, Budapest; NHM, Natural History Museum, London; NMV, Museum of Victoria, Melbourne; NTM, Northern Territory Museum and Art Gallery, Darwin; QM, Queensland Museum, Brisbane; SAMA, South Australian Museum, Adelaide; UQIC, University of Queensland Insect Collection, Brisbane.

Notes on morphology

Australian species of *Ora* and *Scirtes*, like their members in other areas, vary considerably in overall shape – oval, round, flanged, large, small and colour – yellowish, reddish, black, mottled, spotted – but the differences are rarely discreet enough to differentiate species. Significant structural differences are few and I have only found two to be of much taxonomic use: the shape of the metacoxae and the male genitalia (penis and tegmen). The width of the metafemur, shape of the metatrochanter, grooving on the elytral epipleura and the relative size of the eyes are also useful to differentiate some species.

Metacoxae. In *Scirtes* the metacoxal plates are extended backwards in the midline and cover the articulation of the metatrochanters with the coxae. The extensions of the metacoxal plates can be relatively wide and short or almost square, and the hind edge either straight (Fig. 1b) or concave (Fig. 1c). In *Ora* the ventral portion of the extension

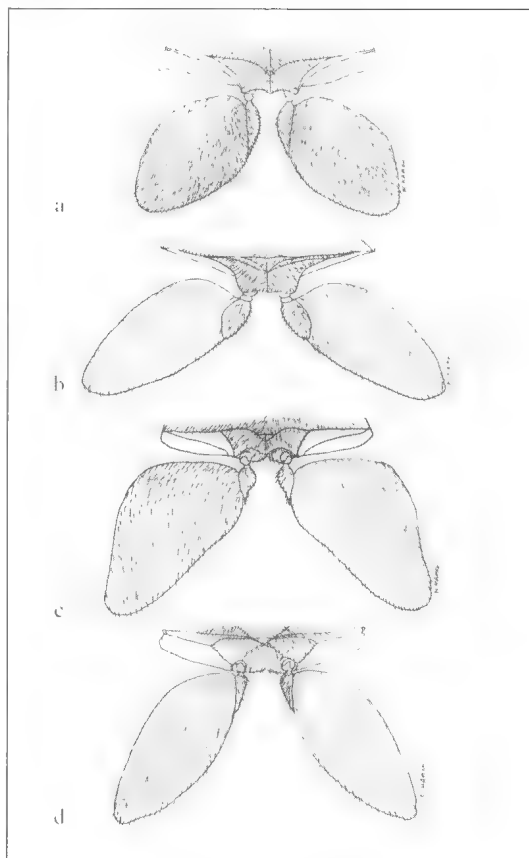


Fig. 1. Metacoxal plates, metatrochanters and metafemurs of; a) *Scirtes auratus* sp. nov.; b) *S. nigerpalpus* sp. nov.; c) *S. tindaleensis* sp. nov.; d) *Ora floccosus* sp. nov. Line = 1.0 mm.

is lacking or virtually so, completely exposing the articulation of the trochanters (Fig. 1d).

Male genitalia. The basic male genitalia of Australian *Ora* and *Scirtes* consists of a penis and a bilobed tegmen situated immediately above it. Enclosing these are modified tergites and sternites of the 8th and 9th abdominal segments (Fig. 2). The nomenclature of the complex and very variable male genitalia of Scirtidae is unsettled. In this paper I follow Nyholm (1972).

Penis. The most common structure for the penis (eg Figs 20-30) of the Australian species consists of an oval "basal piece" ("pala" of Nyholm) with a usually longer distal extension, the "trigonium", which is articulated with it. The basal piece has either one or two parameroids arising from its sides. This ground plan is recognisable in most species but in some, i.e. *O. floccosus* (Fig. 4) and *O. justafloccosus* (Fig. 5), the morphology of the separate pieces is so altered as to obscure their

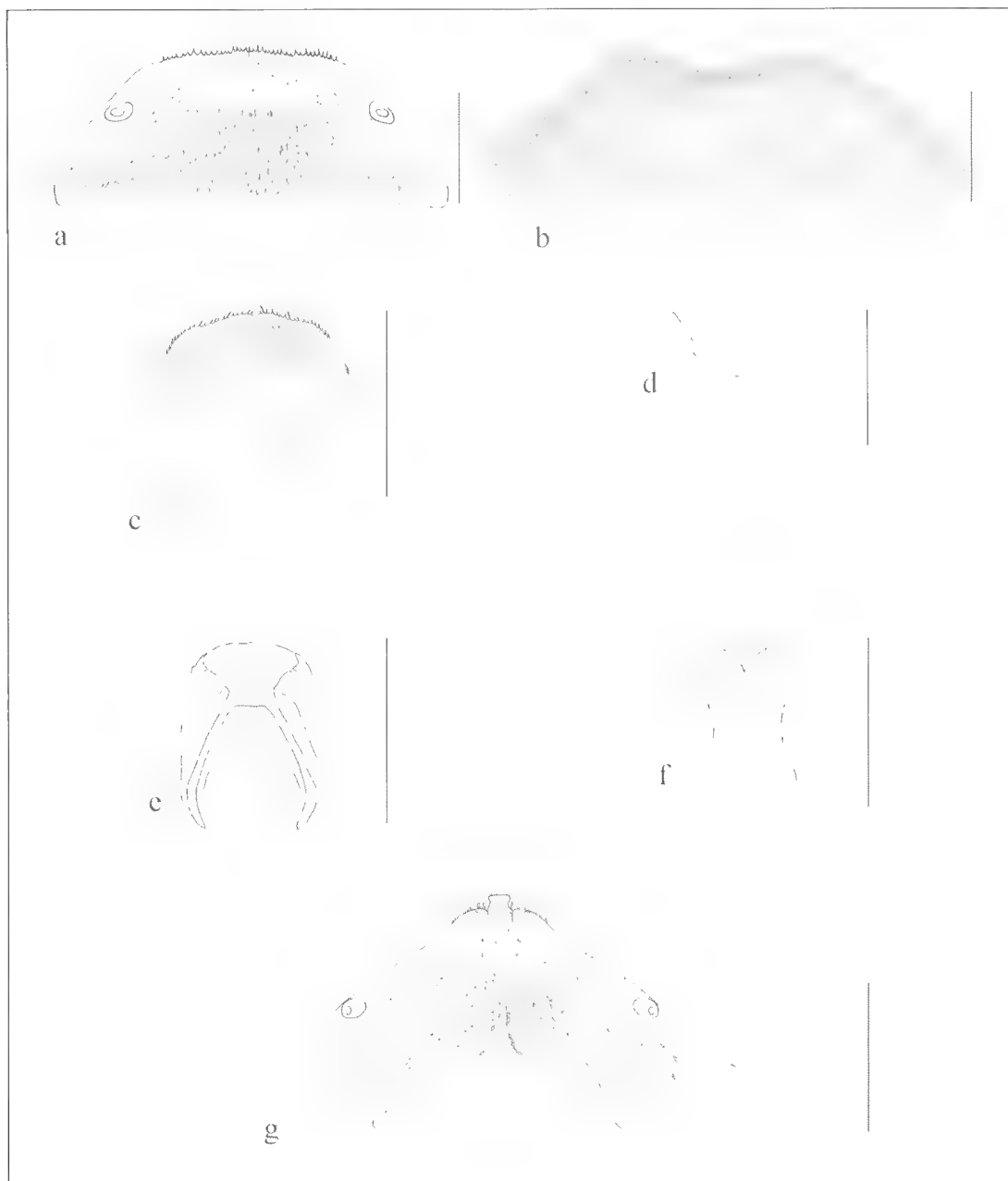


Fig. 2. Terminal abdominal segments of *Scirtes emmae* sp. nov. a) tergite 7; b) sternite 7; c) tergite 8; d) sternite 8; e) tergite 9; f) sternite 9; g) *Scirtes rufotundus* sp. nov. tergite 7. Line = 0.5 mm.

homologies. In one, *S. rufotundus*, the opposite appears to have happened and the structure has been greatly simplified into a unique (for Australian *Scirtes*), small, unstructured penis and a relatively simple tegmen (Fig.15).

Tegmen. The tegmen lies above the penis and is closely attached to it basally. Apically the tegmen consists of two usually symmetrical lobes which can be broad and close together through to long, thin and well separated. These lobes are thought to

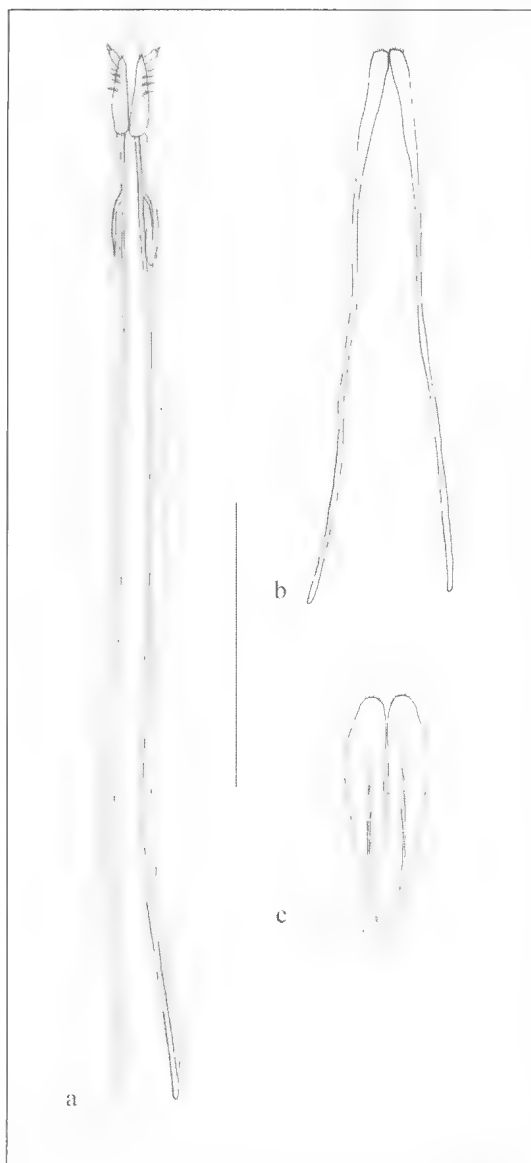


Fig. 3. Female genitalia of *Scirtes emmae*. a) ovipositor; b) tergite 8; c) sternite 8. Line = 1.0 mm.

originate from parameres which are variably and often intimately connected with the tegmen in Scirtidae (Nyholm 1972). In a number of the species described the lobes of the tegmen are broad and wrap around or enclose the penis (eg. Fig. 35), in most of these species portions of the outer edges of the lobes are strongly sclerotized. In *O. floccosus* and *O. justafloccosus* as well as enclosing the penis one lobe is closely articulated with the penis and the other lobe is seamlessly fused to it

(Figs 4, 5).

Abdominal segments (Fig. 2). The 8th and 9th abdominal segments are modified and are only weakly sclerotized. The 8th and 9th tergites are broad structures, each with lateral sclerotized strut-like structures (apodemes) extending backwards. The sternites are less strongly sclerotized, the 8th reduced to a small "U" shaped structure, with the arms pointing apically. The 9th tergite is broadly bilobed apically with a covering of short to medium length setae towards the apex.

Between the species examined there is not a lot of difference in the structure of these segments and I have not used them taxonomically.

Female genitalia (Fig. 3). Within the species examined there is some difference in the detail of the apex of the ovipositor (which is a modified 9th abdominal segment) but it is not great and I have not used it taxonomically in this paper. The ovipositor consists of a long thin basal portion (baculus) with a short two lobed apical piece (coxite) of variable length, with a small appendage at their tips (stylus). Closely attached to the ovipositor is the 8th tergite which has two long, thin, lateral struts/rods. The 8th sternite is similarly shaped but with much shorter lateral struts/rods.

Systematics

Scirtidae with greatly enlarged hind femurs are currently placed into two genera, *Ora* and *Scirtes*, depending on the form of the hind coxal plates. In *Ora* the basal articulation of the metacoxae is exposed (Fig. 1d) whereas in *Scirtes* it is covered at least to some extent (Figs 1b, 1c). Within the Australian species of both genera the general form varies considerably, however the details of the external morphology are very similar which makes any attempt to key the species or to clearly define groupings difficult. In contrast, the form of the male genitalia varies a lot between species, even in those that appear otherwise identical. Because of this many of the new species are essentially defined by the form of the male genitalia.

Nyholm (2002) has used the form of the male genitalia to propose a number of semiformal groups within the Northern Hemisphere members of *Scirtes*. I am not convinced that this approach is warranted at this stage of our knowledge of the Australian species and have not attempted either to use Nyholm's groupings or to propose new groupings. Purely for the convenience of this paper I have used the phrase '*S. helmsi* species complex' for a group of species, including *S. helmsi*, which are virtually indistinguishable on external morphology. On the evidence of the male genitalia they appear unlikely to be monophyletic.

Key to Australian species of *Ora* and *Scirtes*

1. Metacoxal plates lacking ventral portion, completely exposing articulation of metatrochanters (Fig. 1d) (*Ora*).....2
- Metacoxal plates with ventral portion covering all or most of articulation of metatrochanters (Figs 1a-c) (*Scirtes*).....4
2. Dorsal surface mottled; pronotal punctures very small3
- Dorsal surface uniformly dark reddish-yellow; pronotal punctures strong.....*O. improtectus* sp. nov.
3. Penis with three long thin pieces (Fig. 4).....*O. floccosus* sp. nov.
- Penis with two long thin pieces (Fig. 5)*O. justafloccosus* sp. nov.
4. Each elytron with several large white areas; 2.0 – 2.3 mm long.....*S. albamaculatus* sp. nov.
- Elytra without extensive white areas; 2.0 – 5.5 mm long.....5
5. Hind edges of individual metacoxal plates concave.....6
- Hind edges of metacoxal plates straight, slightly convex or slanted towards midline10
6. 2.6 – 3.6 mm long; metatrochanter elongate, 2.5x as long as wide (Fig. 1a); uniformly golden yellow.....*S. auratus* sp. nov.
- 3.2 – 5.5 mm long; metatrochanters 2.0x as long as wide (eg Figs 1b, 1c); reddish-yellow or darker.....7
7. Oval; body setae fine; colour dark chocolate red, hind edges of metacoxal plates weakly concave.....*S. ruforotundus* sp. nov.
- Elongate-oval; body setae strong; colour reddish-yellow; hind edges of metacoxal plates strongly concave.....8
8. Front of frons flat, edge weakly to strongly upturned; antennal segments thick, weakly asymmetric with inner edge larger, particularly in males; elytra reddish-yellow often with darker sides and near scutellum; lobes of tegmen with spines on outside, tip of penis hooked. (Fig. 12).
.....*S. kaytae* sp. nov.
- Front surface of frons evenly rounded, front edge not upturned; antennal segments relatively thin, symmetrical; elytra uniformly reddish-yellow; lobes of tegmen smooth, tip of penis not hooked.....9
9. Sides of elytra subparallel; dark reddish-yellow; tips of tegmen slightly bulbous, triangular extension near bases of lobes (Fig. 16); tip of penis with three thin lobes, (Fig. 16).....*S. tindaleensis* sp. nov.
- Oval; light reddish-yellow tending darker towards front; tegmen lobes with small triangular extension on outside near apex (Fig. 9) *S. emmae* sp. nov.
10. 2.0mm long; almost round; elytra dark.....*S. microrotundus* sp. nov.
- 2.0 – 5.1 mm long; oval rather than round; elytra variable in colour.....11
11. 4.5 – 5.0 mm long; uniformly light reddish-yellow (some specimens with vague darker pattern on pronotum); elytra flanged*S. macroconcolor* sp. nov.
- 2.0 – 5.1 mm long; colour variable but never uniformly reddish-yellow in species > 4.0 mm long; elytra variably flanged12
12. Head, pronotum and often elytra with dark/light colour pattern; epipleuron weakly grooved in front half; 3.5 – 5.0 mm long.....13
- Without colour pattern (except occasionally on head and pronotum); 1.8 – 4.3 mm long; epipleuron flat except at extreme front.....(*S. helmsi* species complex. Only distinguishable on characters of male genitalia. See separate key below.)
13. Elytron with 3-4 disrupted darker stripes, elytron quite strongly flanged towards front.....*S. interstinctus* sp. nov.
- Elytron without linear markings, either uniformly reddish yellow or with darker bases and sides; elytron at most weakly and narrowly flanged.....*S. exoletus* Waterhouse

Key to males of the *S. helmsi* species complex

1. Small (2.2 – 2.5 mm). Trigonium long and thin with apex bent at right angles (Fig. 32), single parameroid long, thin, sinuous; tegmen broad, lobes short and slightly asymmetric (Southwestern Western Australia)*Scirtes pygmaeus* sp. nov.
- Not with above combination of characters.....2
2. One lobe of tegmen extremely long and thin, closely associated with elongate trigonium and projecting well beyond apex of trigonium (Fig. 26) (Southwestern Western Australia)*Scirtes nalyerinensis* sp. nov.
- Tegmen lobes symmetrical or nearly so, tips never projecting much beyond apex of trigonium3
3. Tegmen with two, well-separated finger-like lobes (eg. Fig. 24); trigonium of penis elongate > twice length of basal piece (eg. Fig. 40); one or two parameroids with the larger one elongate and usually with a hooked end (eg. Fig. 40)4
- Lacking above combination of characters: tegmen often with lobes broad and poorly separated (eg. Figs 31-33); trigonium of penis variably shaped, about same length or shorter than basal piece (eg. Figs 21, 29, 34); parameroid(s) variable but usually not elongate with hooked end10

4. With well developed second parameroid (right hand one) which is one quarter to one third length of main parameroid (left hand one) (Figs, 27, 28, 33, 37)..... 5
Usually without second parameroid (Figs 20, 30, 24), if present, < a quarter length of main parameroid which is strongly hooked at apex (Fig.38).....8
5. Dark coloured, with dark antennae and palpi; elytron not flanged; trigonium of penis broad, tip rounded, slightly upturned. (Figs 27, 42)
.....*S. nigerpalpus* sp. nov.
Light coloured with pale palpi and at least the basal segments of antennae pale; elytra weakly flanged towards front; trigonium of penis narrower (Figs 28, 37).6
6. Main parameroid sinuate towards apex (Figs 37, 44), penis approximately 0.4x length of body
.....*S. victoriaensis* sp. nov.
Main parameroid with apical hook, penis approximately 0.2x length of body7
7. Much of body dark. Largest parameroid with abrupt hook (Figs 33, 41).....
.....*Scirtes rivularis* sp. nov.
Body more or less uniformly yellowish. Largest parameroid hook not abrupt (Figs 28, 43)
.....*S. orientalis* sp. nov.
8. Penis golfclub-shaped; trigonium long and thin, tip sharp, (Figs 24, 40).....*S. helmsi* Blackburn
Penis with apex expanded dorsal/ventrally near tip (Figs 20, 30, 38, 39).....9
9. Usually with very small right hand parameroid, left hand (main) parameroid with well-defined hook at apex (Figs 20, 38)... *S. brisbanensis* Pic
Only one parameroid, with long hook (Figs 30, 39).....*S. pinjarraensis* sp. nov.
10. Trigonium of penis short 0.4x length of basal piece, strongly beak-shaped (Fig. 19).....
.....*S. beccus* sp. nov.
Trigonium of penis at least 0.75x length of basal piece, not beak-shaped11
11. Trigonium of penis asymmetrical, with prominent spine on inside (Fig. 25).....
.....*S. musica* sp. nov.
Trigonium of penis more or less symmetrical, without spine on inside (eg Fig. 23).....12
12. Penis with two distinct parameroids (Fig. 21)....
.....*S. calmi* sp. nov.
Penis with only one parameroid (eg. Fig. 23) .13
13. Parameroid of penis swan-like (Fig. 23).....
.....*S. cygnus* sp. nov.
Parameroid of penis more elongate, not swan-like.....14
14. Tegmen with lobes thin, well separated (Figs 18, 22, 29, 31)15
Tegmen with lobes broad, partly separated, tending to wrap around and enclose penis (Figs 17, 34, 35, 36)18
15. Tegmen with lobes with distinct brush of setae near apex (Fig. 29)*S. peniculus* sp. nov.
Tegmen lobes without setae16
16. Penis complex, parameroid much larger than trigonium (Fig.18).....*S. baroalba* sp. nov.
Penis of more usual form, trigonium larger than parameroid (Figs 22, 31).....17
17. Parameroid hooked at apex, about two-thirds length of trigonium; tegmen lobes with serrated inner edges near apex (Fig. 22).....
.....*S. crassiantennae* sp. nov.
Parameroid of penis not hooked, about same length as trigonium; lobes of tegmen smooth (Fig.31)*S. podlussanyi* sp. nov.
18. Penis with trigonium broad (Fig. 34).....
.....*S. spatula* sp. nov.
Penis with trigonium thin (Figs 17, 35, 36)....19
19. Penis with parameroid elongate, without apical hook, nearly as long as trigonium (Fig. 35).....
.....*S. storeyi* sp. nov.
Penis with parameroid short, either sinuate or hooked at apex (Figs 17, 36).....20
20. Body uniformly light reddish-yellow except for darker head in some; parameroid of penis stout (Fig.17); 2.2 – 2.6 mm long.....
.....*S. alastairi* sp. nov.
Dorsal surface chestnut, segments of antennae paler, shoulders of elytra and triangular patch at apex of elytra lighter, parameroid of penis more elongate (Fig. 36); 3.1 mm long
.....*S. triangulus* sp. nov.

Ora Clark, 1865

(Species listed in alphabetic order.)

Ora floccosus sp. nov.

(Fig. 4)

Types.

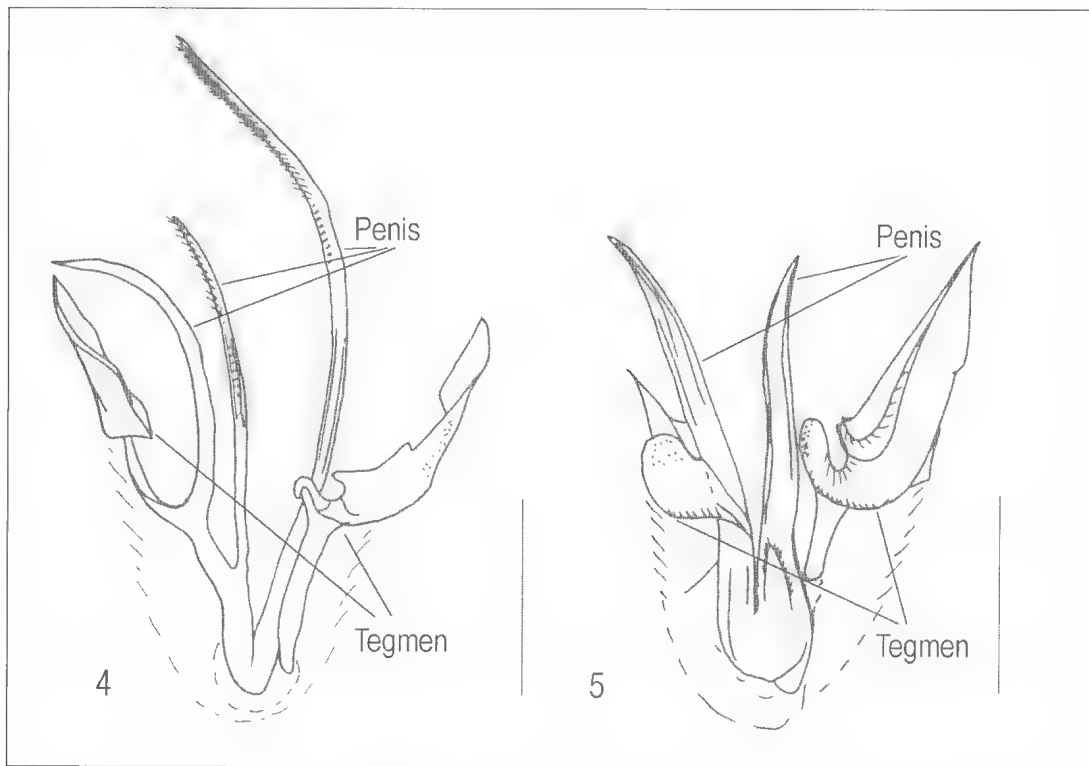
Holotype

male; " AUSTRALIA 99.1.13 Queensland, Pinnocle village (camping) leg. A. Podlussany", SAMA. *Paratypes*: 3; 1, "Cow Bay N of Daintree, N Qld. 27.xii.83 – 20.i.1984, I. C. Cunningham", QPIM; 1, "Edge Hill Cairns, at light, 24/4/65, J.G.Brooks", microscope slide, ANIC; 1, "AUSTRALIA n Qld 15 km NNW of South Johnstone Light Trap Nov 1987 Fay & Halfpapp", QPIM.

Description (number of dissected males examined, 4)

Habitus. Length 3.3 – 4.2 mm., relatively flat, broadly oval.

Head. Light yellow-brown with darker patches; antennae light yellow-brown. Small, width between eyes about 2.3x dorsal width of eye; slightly



Figs 4-5. Dorsal views of tegmen and penis. Lines = 0.5mm. 4. *Ora floccosus* sp. nov. 5. *O. justafloccosus* sp. nov.

depressed inwards from eyes. Punctures small, moderately dense, each with a prominent whitish seta. Frons with sides slightly diverging, front edge straight or very weakly concave, edges weakly beaded. Segment 1 of antenna large, barrel-shaped; segment 2 smaller, barrel-shaped; segment 3 a little longer but narrower; segments 4-10 longer, broader, particularly middle ones; segment 11 a little longer than segment 10; segments quite thickly covered with short whitish setae.

Pronotum. Light yellow-brown with darker mottlings. Short, broad. Puncture small, even, moderately dense, each puncture with a whitish seta. Hind angles obtuse, front angles moderately extended forward, sides weakly beaded.

Scutellum. Light yellow - brown. Sides approximately equal length, lateral two weakly convex. Punctures small, weak.

Elytron. Light yellow-brown with darker mottlings. Sides widely flanged in middle particularly over metafemurs. Densely punctured punctures of uneven sizes, each puncture with a short whitish seta. Epipleuron wide in front quarter, widest some distance from shoulder, then narrowing evenly to near apex, weakly concave particularly near front.

Ventral surface. Light reddish-yellow. Pronotal process very narrow along whole length. Mesosternum with narrow groove for reception of pronotal process; tip just reaching to level of mesocoxae. Front triangular midline extension of metasternum narrowly triangular, strongly beaded; rear midline extension broad, more than twice as wide as long. Metacoxal plate a little wider than long, ventral part of plate virtually absent, completely exposing articulation of metatrochanter; anteriolateral angle extending narrowly some way along metasternum; sides weakly beaded; posteriolateral angles sharply pointed. Metatrochanter small, about 2.0x as long as wide. Metafemur moderately swollen, widest in middle, hind edge with large notch near apex. Notch bordered with v-shaped raised ridge. Dorsal metatibial spine relatively long, a little longer than twice size of ventral spine and about three quarters length of segment 1 of metatarsus. Segment 1 of metatarsus a little longer than other segments combined. Ventrites with punctures small, dense, each with a short fine seta; reticulation moderate, fine, more pronounced towards rear; apex of apical ventrite truncated or weakly concave.

Male

Little external difference between sexes. Penis complex (Fig. 4). The trigonium appears to consist of three long thin pieces joined to each other near their bases. Penis lacking basal piece. Tegmen lobes asymmetrical, complex, one roughly sickle-like with the blade-like top portion closely enclosing one of the trigonium pieces and the handle-like lower portion closely held to but not fused with the trigonium piece (Fig. 4). The other lobe of the tegmen has its base seamlessly fused to a piece of the trigonium and the upper portion closely enclosing another piece of the trigonium. (The figure illustrates the genital capsule slightly teased apart: in life the tegmen lobes tightly enclose the three pieces of the trigonium.)

Variation

The strength of the notch on the hind femur and the strength of the colour pattern are variable.

Referred specimens – all female

1, Bramston Beach, near Innisfail, N Qld. 30 April 1976, D. H. Colless (open savanna), ANIC; 4, Cairns, 2/50 G B, J. G. Brooks Bequest 1976, ANIC; 1, Russell R. at Bellenden Ker Landing NQ, 5m, 24 Oct – 9 Nov. 1981, EARTHWATCH/QLD MUSEUM, ANIC COLEOPTERA Voucher # 83-0588, QM

Etymology

Latin, "floccosus" – woolly.

Notes

This species and the very similar *O. justafloccosus* are distinctive species with widely flanged elytra and a generally 'woolly' appearance including the antennae and tarsi. These two species are separated most readily from *O. improtectus* by their mottled colouration and small pronotal punctures. *Ora floccosus* and *O. justafloccosus* can only be separated by the form of the male genitalia.

Ora floccosus appears to be a more southern species from around Cairns and *O. justafloccosus* more northern from around Iron Range. However too few male specimens are known to have much confidence in this geographic separation.

Ora improtectus sp. nov.

(Fig. 6)

*Types**Holotype*

male; "Stuart Range Q Jan Feb 1927 Hale & Tindale", SAMA.

Paratypes

42; 1, "15 54S 163 32E Batten Point, 30 km NE

by E Borroloola, NT, 30 Oct.1975, M. S. Upton", ANIC; 2, "Cairns, 2/50, G.B". "J. G. Brooks Bequest, 1976", ANIC; 1, "Cairns 7-10-34" J. G. Brooks Bequest 1976", ANIC; 2, "Cairns dist., E. Allen" "I 52 52", SAMA; 2, "Halfide nr Mackay NEQ 8.ii.65 E. C. Dahms" QM; 1, "12.26S 130.56E Holmes Jungle, Berrimah 10km S of Darwin, NT, 8.xi.72, at light, E. Britton", ANIC; 5, "King R NT 10-1-16", NMV; 14, ditto, 7-1-16, 10 NMV, 4 slides SAMA; 3, "King R NT Coll by W. McLemman esq and pres by H. L. White esq 14.10.16", NMV; 1, "15 04S 145 07E Mt Webb Nat. Pk. QLD, 28 - 30 Sept 1980, T. Weir", ANIC; 1, "Nassau River NW Dunbar Stn., 18 Nov. 1983, A. Walford-Huggins", ANIC; 6, "Thursday Island, 10/52, CM", "J. G. Brooks Bequest 1976", 5 QPIM, 1 slide SAMA. 2, "Thursday Isl NQ Oct-1952", NMV; 1, "Smith Point NT 1.viii.1982 C.Wilson & S. Collins", "ex light trap", NTM; 1, "Stuart Range Q Jan – Feb 1927 Hale & Tindale", SAMA.

Description (number examined, 43)

Habitus. Length 2.5 – 3.6 mm., relatively flat, oval.

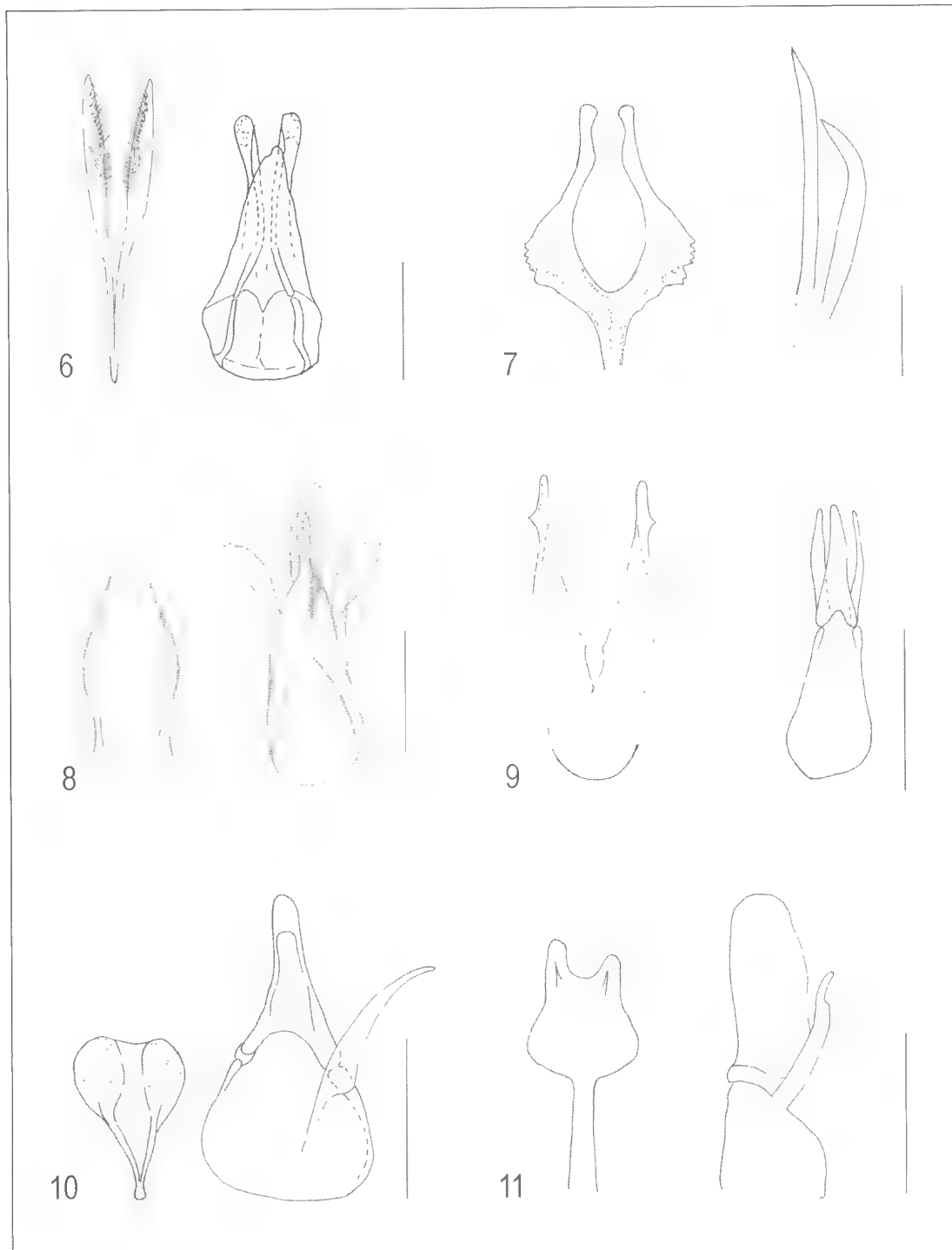
Head. Reddish-yellow to dark reddish-yellow; antenna light reddish-yellow. Small, width between eyes about 2.0x dorsal width of eye. Moderately and evenly punctate, each puncture with a relatively long setae. Frons with sides slightly diverging, front edge straight or very weakly concave, edges beaded. Segment 1 of antenna large, cylindrical slightly curved at base; segment 2 much smaller, cylindrical; segment 3 as long as segment 2 but a little narrower; segments 4 – 10 long, narrow, cylindrical, becoming progressively slightly smaller; segment 11 slightly longer than segment 10, moderately setose.

Pronotum. Reddish-yellow to dark reddish-yellow. Short, broad. Evenly covered with strong punctures, becoming almost confluent at sides, each puncture with a moderately long golden seta. Hind angles obtuse, front angles moderate produced forward, sides beaded.

Scutellum. Reddish-yellow, tending to be lighter than elytra. Sides approximately equal length, lateral two convex; punctures large, well separated.

Elytron. Reddish-yellow to dark reddish-yellow on disc becoming darker laterally and towards apex. Sides weakly and narrowly flanged, more strongly towards front. Moderately dense strong punctures, each puncture with a short yellow seta. Epipleuron relatively wide in front quarter becoming much narrower over rest of elytron, front portion with wide shallow longitudinal depression in many.

Ventral surface. Reddish-yellow with diffuse darker patches. Pronotal process very narrow between procoxae, apical portion not much wider. Mesosternum with narrow triangular groove for



Figs 6-11. Dorsal views of tegmen (left) and penis (right). Lines = 0.5 mm. 6. *Ora improtectus* sp. nov. 7. *Scirtes albamaculatus* sp. nov. 8. *S. auritus* sp. nov. 9. *S. emmae* sp. nov. 10. *S. exoletus* Waterhouse. 11. *S. interstinctus* sp. nov.

reception of pronotal process; tip reaching just to level of front edge of mesocoxae. Front midline extension of metasternum narrowly triangular, beaded. Rear triangular midline extension of mesosternum broad, about twice as wide as long. Metacoxal plate a little wider than long, anterio-lateral corner extending some way along mesosternum, ventral portion of plate absent towards rear, exposing articulation of metatrochanter; sides beaded; posteriolateral angle sharp. Metatrochanter small, about 2.0x as long as wide. Metafemur greatly swollen, widest well before middle, hind edge with moderate notch near apex; reddish-yellow, diffusely darker in places. Dorsal metatibial spine moderately long, about twice length of ventral spine and nearly as long as segment 1 of metatarsus. Segment 1 of metatarsus a little longer than other segments combined. Ventrites reddish-yellow, often with diffuse darker areas; punctures rather sparse, very small, reticulation, strong, fine, more pronounced laterally; apex of apical ventrite truncated or weakly concave.

Male

Little external difference between sexes. Basal piece of penis short, rather square; trigonium much longer and for much of its length separated into two elongate parts with rounded tips, a broadly triangular thin structure lies on top of the trigonium for much of its length (Fig. 6). Tegmen longer than penis, lobes well separated, thin, with strong setae on inner edge in apical half (Fig. 6).

Variation

Colour varies from reddish-yellow to dark reddish-yellow.

Etymology

Latin. "Improtectus" unprotected, a reference to the unprotected metatrochanters.

Notes

A small northern species separated from *O. floccosus* and *O. justafloccosus* by its smaller size, uniform rather than mottled dorsal surface and strong pronotal punctures. In contrast to *S. floccosus* and *S. justafloccosus*, the male genitalia are relatively normal. The tegmen is unique in having strong setae/spines on the inside towards the tips.

Ora justafloccosus sp. nov. (Fig. 5)

Types

Holotype

male "12.43S 143.18E, 11 km ENE of Mt Tozer QLD, 11-16 July 1986, T. Weir & A. Calder", ANIC.

Paratypes

3, male; 1, "Iron Range, Cape York Pen. N. Qld. 26 31 May 1971. G. Monteith" "UQIC Reg# 53698", UQIC; 1 slide, ditto, "11 - 17 May 1968 UQIC Reg# 53696", UQIC; 1, "12.43S 143.17E 9km ENE Mt Tozer QLD 5 - 10 July 1986 T. Weir & A. Calder", ANIC; 1, "15 03S 143 09E 3 km NE Mt Webb QLD 30 April - 3 May 1981 A. Calder", ANIC.

Description (number examined, 4).

As for *O. floccosus* except as follows.

Male

Penis consisting of two long thin pieces, slightly grooved and not as long as in *O. floccosus* (Fig. 5). One lobe of tegmen relatively similar to *O. floccosus* (Fig. 4) the other lobe fused to penis much nearer its apex than in *O. floccosus* (Fig. 5).

Etymology.

Latin. "Juxta" - near. A reference to its close appearance to *S. floccosus*.

Notes

See under *O. floccosus*.

Referred specimens - all female

1, Captain Billy Creek Cape York Pen, N Qld, 142.50E 11.40S. 9 - 13/7/75, G. B. Monteith, QM; 1, Iron Range Cape York Pen. N. Qld. 11 - 17 May 1968, G. Monteith, UQIC Reg# 53695, UQIC; 3, Iron Range Cape York Pen. N. Qld. 16 - 23/11/65, G. Monteith, UQIC Reg# 53692, 88 - 89, UQIC; 1, Iron Range Cape York Pen Qld 28 April - 5 May 1968, G. Monteith, UQIC Reg# 53697, UQIC.

Scirtes Illiger, 1807

a) Species other than those in the *S. helmsi* species complex. Arranged in alphabetic order.

Scirtes albamaculatus sp. nov. (Fig. 7)

Types.

Holotype

female; "Cairns Queensland F.H. Taylor", ANIC.

Paratypes

4; 1, "AUSTRALIA, Qld Bramston Beach Eubenangee Swamp, 4.v.1987, J.K. Bulcjunas, collected on *Melaleuca quinquenervia*", ANIC; 1, Cape Tribulation, 8.1.1983, R. Storey, At Light, QPIM; 1, "Cape Tribulation, 1 Aug - 15 Sept 1987, A Walford - Huggins, coastal rainf. NQ, intercept trap, ANIC; 1 slide, Cow Bay N of Daintree, 25.1 7.2 1984, I. C. Cunningham, SAMA.

Description (number examined, 5)

Habitus. Length 2.0 – 2.3 mm., relatively flat, oval.

Head. Reddish-yellow, antenna yellowish. Small, width between eyes about 3.2x dorsal width of eye. Moderately and evenly punctate. Frons with sides moderately converging, front edge slightly concave, edges weakly beaded. Segment 1 of antenna large, barrel-shaped; segment 2 about same shape and size, segment 3 about half as long and narrower; segments 4 – 10 same length as segment 2, cylindrical, progressively becoming slightly broader and flatter, segment 11 a little longer than segment 10.

Pronotum. Reddish-yellow to dark reddish-yellow, disc somewhat darker, with slight darker markings. Short, broad. Evenly and moderately punctate, each puncture with a moderately long golden seta. Hind angles obtuse, front edge sinuate, front angles weakly projected forwards, sides weakly beaded.

Scutellum. Reddish-yellow to dark reddish-yellow. Sides approximately equal length, lateral two slightly convex.

Elytron. Reddish-yellow to dark reddish-yellow, with two large areas of dirty white. Sides beaded rather than flanged. Moderately and evenly punctate, each puncture with a short yellow seta. Epipleuron yellowish with colour varying to reflect elytron colour, moderately wide in front quarter, becoming much narrower over rest of elytron, central area of front portion widely depressed slightly.

Ventral surface. Dark reddish-yellow with lighter areas, appendages tending lighter. Pronotal process very narrow. Mesosternum with relatively broad, triangular groove for reception of pronotal process; tip reaching past level of mesocoxae. Front extension of mesosternum small, in shape of equilateral triangle; rear midline extension in midline large about twice as wide as long. Metacoxal plate wider than long, anteriolateral corner extending some way along metasternum; hind edge slightly concave, slanting strongly to midline; length of midline short, about as long as midline of triangular backward extension of mesosternum; sides weakly beaded; posteriolateral angles bluntly pointed. Metatrochanter small, elongate, about 3x as long as wide. Metafemur greatly swollen, widest near middle. Dorsal metatibial spine moderately long, about twice size of ventral spine and a little over three quarters length of segment 1 of metatarsus. Segment 1 of metatarsus a little longer than other segments combined. Ventrites with punctures small, shallow; reticulation, moderate, fine, more pronounced towards rear; apex of apical ventrite truncated or weakly concave.

Male

Little external difference between the sexes. The only available preparation of the male genitalia is

poor. From what can be made out the genitalia are comparatively small and complex (Fig. 7). There are at least two long (? trigonium) pieces to the penis reminiscent of species such as *O. floccosus*. The lobes of the tegmen are narrow, bluntly tipped and well separated (Fig. 7).

Variation.

Little variation within the five known specimens, except in the shape of the white areas on the elytra, with one specimen having the front patch broken up into two discreet patches on each elytron.

Etymology

Latin. "Albus"- white, "macula"- spot, a reference to the white spots on the elytra.

Notes

A distinctive small species, with small eyes and several distinct white patches on its otherwise dark elytra, a large segment 2 of the antenna and elongate metatrochanters. The hind edges of the metacoxal plates are slightly concave and slant strongly backwards towards the midline resulting in the midline suture being relatively short compared to other species.

Scirtes auratus sp. nov.

(Figs 1, 8)

Types

Holotype

male, "Qld. Townsville 10km NW 23/3/96 C. Watts", SAMA.

Paratypes

34; 1, "Homestead, Silver Plains Via Coen, N. Qld. 11.x11, 1964 G. Monteith" "UQIC Reg# 53649", UQIC; 25, "Ross R. Dam Spillway Townsville, NQ 1 Dec. 1986 T. Vernon ex *Melaleuca leucodendra*", ANIC; 1, "2k N Mt Molloy Qld. 5.2.97 C. Watts", SAMA; 3, "5k N.W. Mt Molloy Qld. 5.2.97 C. Watts", SAMA; 2, "Nardello's Lagoon Qld. 6.2.97 C. Watts", SAMA; 1, "Qld. Bushland Beach 20km N Townsville A. J. Watts 23 – 30/12/97", SAMA; 1, "Qld. Bushland Beach 20km N Townsville, at light, A. J. Watts 16 – 18 Jan 1998", SAMA.

Description (number examined, 110)

Habitus. Length 2.6 – 3.6 mm, relatively flat, oval.

Head. Light reddish-yellow, antennae light reddish-yellow. Small, width between eyes about 2.8 x dorsal width of eye. Quite strongly and evenly punctate, well covered with long golden setae. Frons with sides diverging in front of antennal base which is deeply excised into side of head; front edge straight or very weakly concave, edges not beaded.

Segment 1 of antenna large, barrel-shaped; segment 2 smaller, barrel-shaped; segment 3 smaller and narrower; segments 4–10 long, rectangular, flattish; segment 11 a little longer than segment 10, quite strongly setose.

Pronotum. Light reddish-yellow, sometimes with diffuse darker mottlings or patterns. Short, broad. Evenly and moderately punctate, stronger laterally, each puncture with a long golden seta. Hind angles obtuse, antero-lateral angles moderately produced, sides weakly beaded.

Scutellum. Light reddish-yellow. Relatively large, sides approximately equal length, lateral two weakly convex; punctured as on pronotum.

Elytron. Light reddish-yellow with diffuse darker areas in some. Sides weakly and narrowly flanged in front third. Moderately and evenly punctate, each puncture with a short yellow seta. Epipleuron relatively wide in front quarter becoming much narrower over rest of elytron, front portion widely and shallowly grooved.

Ventral surface. Light reddish-yellow, sometimes with diffuse darker areas. Pronotal process very narrow. Mesosternum with narrow groove for reception of pronotal process, tip reaching past level of front margin of mesocoxae. Front midline extension of metasternum relatively small, sharply triangular; rear midline extension of metasternum broad, at least twice as wide as long, apex rounded. Metacoxal plate a little longer than wide, with antero-lateral corner extending some way along metasternum; hind edge moderately concave, posterior-lateral angles sharply pointed. Metatrochanter narrow, elongate, about 2.5x as long as wide (Fig. 1). Metafemur greatly swollen, widest just before middle, moderate indentation on hind edge near base. Dorsal metatibial spine relatively short, about twice size of ventral spine and about half-length of segment 1 of metatarsus. Segment 1 of metatarsus a little longer than other segments combined. Ventrites with punctures small, shallow; with moderate fine reticulation, more pronounced towards rear; apex of apical ventrite strongly concave.

Male

Penis complex, two equal sized fleshy lateral lobes (? parameroids), trigonium trilobed with central lobe with small, strongly chitinized, serrated structure at its base (Fig. 8). (An alternative interpretation is a single lobed trigonium and upper and lower pairs of parameroids.). Tegmen lobes shorter than penis, elongate, thin, pointed, well separated, some quite strong spines on outside edge (Fig. 8).

Variation

Colour varies from light reddish-yellow to a

golden yellow, with head and pronotum with diffuse darker areas or even distinct dark patterning in some.

Etymology

Latin, "Aurum" – gold, a reference to the colour of the beetle.

Notes

A relatively small, noticeably golden species with weakly concave hind edges to the metacoxal plates and relatively long, elongate, metatrochanters. Equally distinctive are the male genitalia which are unusually complex for Australian *Scirtes*, with fleshy parameroids and a small asymmetric, heavily chitinized, structure in the centre.

I have reared the species from larvae, also relatively golden, collected from among *Typha* in a shallow semi-permanent small lake. Adults were collected from the emergent rushes.

Specimens examined

Queensland. 2, Arriga via Mareeba, 16/10/85, K. N. Halfpapp, ex rice paddy, QPIM; 3, Cairns, 2/50, G. Brooks, ANIC; 1, Cardstone, 3–4/12/66, J. C. Brookes, ANIC; 1, Ingham, K. J. Sandery, 29/5/23, ANIC; 1, Christmas Creek, 15 K W of Fairview via Laura, 26–27/6/73, G. B. Monteith, QM; 1, Cow Bay N of Daintree, 18–25/1/84, I. C. Cunningham, QPIM; 1, 3mi SSW of Millaa Millaa, 30/10/68, R. J. Elder, ANIC; 2, Mossman, 8/1/84, at light, J. D. Brown, QPIM; 3, 2 mi SW of Mt Inkerman, 19 45S 147 30E, 11/12/68, S. Misko, ANIC; 7, 4mi W of Mourilyan, 5/11/66, sandy soil at light, E. Britton, ANIC; 5, Ditto, 11/66, G. Brooks, ANIC; 1, Pinnocle Village, 13/1/99, A. Podlussany, HUNG; 1, Rocky River via Coen, 10mi N, G. Monteith, UGIC Reg# 53654; 1, 15km WNW South Johnstone, 9/5/86, at light, Fay & Halfpapp, QPIM; 2, Tolga, 10/1/86, at light, QPIM; 1, Walkamin, 15/3/84, at light, J. D. Brown, QPIM. **Northern Territory.** 1, Berry Springs, 30km SSE of Darwin, 11/11/72, at light, E. Britton, ANIC; 3, 7km NW by N of Cahills Crossing, East Alligator River, 12, 23S 132.56E, 27/5/73, E. G. Matthews, ANIC; 1, 5 km NNW of Cahills Crossing East Alligator River, 12, 23S 132.57E, 28/5/73, E. G. Matthews, ANIC; 1, Cahills Crossing East Alligator River, 12 26S 132 58E, 29/5/73, at light, E. G. Matthews, ANIC; 1, Cannon Hill via Jim Jim, 18/8/71, T. Weir & A. Allwood, NTM; 1, Finnis River Station, 2/4/86, C. Wilson, ANIC; 2, Fogg Dam, 16/2/87, on *Sida cordifolia*, ANIC; 1, CSIRO HQ Kalpalga, 12.40S 132 22E, 19/6/79 (mv light), G. Monteith & D. Cook, QM; 1, 10km N Jabiru, 21/9/82, R. I. Storey, at light, QPIM; 5, Jubiru, R. I. Storey, 17–20/9/82, QPIM.

Scirtes emmae sp. nov.

(Figs 2, 3, 9)

*Types**Holotype*

male, "Cardstone QLD 15.xi.1966 J. G. Brooks", ANIC.

Paratypes

21; 1, "Qld. Bushland Beach 20km N Townsville, 23 – 30/12/97. A. J. Watts", SAMA; 1, "Cairns Q Dec 50 J.G. Brooks, NMV; 1, "Cape Tribulation, N. Qld. 24-29.xii.1980 R. I. Story & N. Gough Rainforest", QPIM; 4, "Cape Tribulation, N Qld. 8.1.1983, R. I. Story, at light" QPIM; 1, "Cardstone QLD 16.xi.1966 J. G. Brooks", ANIC; 1, "Cardstone QLD 19.xi.1966 J. G. Brooks", ANIC; 2, "Cardstone, N.Q. xi.66. K. Hyde", ANIC; 2, "Flying Fish Pt. 21/1/65 E. G. Dahms, QM; 3, "N.T. 12.35S 131.20E Kemp Airstrip Rainfor. 24 – 25 July 1979, G. Monteith & D. Cook", QM; 1, "Killymoon Ck. 25 k S Townsville Qld., 2.2.97, C. Watts", SAMA; 1, "AUSTRALIA Northern Territory Mt Bunday, 144m" 13 13 58S 131 08 018E, 4 – 6 xi 2000, leg. A. Podlussany", HUNG; 3, "AUSTRALIA 99.1.13 Queensland, Pinnocle village (camping) leg. A. Podlussany", HUNG.

Description (number examined, 107)

Habitus. Length 3.3 – 4.3 mm., relatively flat, oval.

Head. Reddish-yellow to dark reddish-yellow. Small, width between eyes about 2.2x dorsal width of eye. Strongly, densely and evenly punctate, each puncture with a long golden seta. Frons with front angles bulging outwards and may be slightly bent upwards, front edge straight or very weakly concave, edge strongly beaded. Segment 1 of antenna large, barrel-shaped; segment 2 about half as long, cylindrical, segment 3 as long as segment 2, narrower; segments 4 – 10 long, narrow, cylindrical; segments 10 and 11 subequal.

Pronotum. Reddish-yellow to dark reddish-yellow. Short, broad. Evenly and quite densely punctate, punctures moderately strong, confluent at sides, each with a long golden seta. Hind angles obtuse, front edge strongly sinuate, sides weakly beaded.

Scutellum. Reddish-yellow; a little longer than broad, lateral sides weakly convex.

Elytron. Reddish-yellow. Quite strongly and evenly punctate, each puncture with a yellow seta although often abraded off. Weakly flanged towards front. Epipleuron yellow, relatively wide in front quarter, becoming much narrower evenly over rest of elytron.

Ventral surface. Light reddish-yellow. Pronotal process very narrow between procoxae, apical

portion not much wider, strongly keeled. Mesosternum with narrowly elongate groove for reception of pronotal process; tip reaching level of mesocoxae. Rear triangular midline extension of metasternum narrower than front extension; front extension about twice as wide as long. Metacoxal plate broader than long with antero-lateral corner extending some way along metasternum; hind edge strongly concave; sides beaded; posteriolateral angles rounded. Metatrochanter small, apex pointed. Metafemur greatly swollen, widest just before middle, quite strongly indented on hind edge near apex. Dorsal metatibial spine relatively long, more than twice size of ventral spine and about two thirds length of segment 1 of metatarsus. Segment 1 of metatarsus a little longer than other segments combined. Ventrites with punctures small, shallow; reticulation moderate, fine, more pronounced towards rear; apex of apical ventrite truncated or concave.

Male

No external difference between sexes. Basal piece of penis oval; trigonium a little shorter than basal piece, elongate, triangular, tip rounded; two similarly shaped parameroids, as long as trigonium (Fig. 9). Tegmen longer than penis, partially enclosing penis, lobes well separated with small triangular extensions on the outside near apex (Fig. 9).

Variation

Some specimens are uniformly reddish-yellow whereas the majority are darker towards the front.

Etymology

Named after my granddaughter Emma, whose father collected many of the specimens.

Notes

A relatively large species from tropical north and eastern Australia. Typical specimens are oval, reddish and with the colour becoming noticeably darker towards the front.

Broadly sympatric with the other two large reddish-yellow, elongate-oval species with concave hind margins to the metacoxal plates, *S. kaytae* and *S. tindaleensis*. *Scirtes tindaleensis* is more elongate and usually darker in colour; *S. kaytae* has upturned frons and asymmetric antennal segments and usually has dark regions towards the sides of the elytra. The male genitalia of all three species are very distinctive and even if only the tips are visible readily identify the species.

Additional specimens examined

Northern Territory. 1, Black Point Coburg Pen., 11 09S 132 09E, 15 – 23/2/77, T. A. Weir, ANIC; 1,

Berry Springs 30 km SSE Darwin 12 41S 130 58E, 11/11/72, at light, E. Britton, ANIC; 3, Casurina Beach 10km NNE Darwin 12 21S 130 42E, 22/10/72, E. Britton, ANIC; 4, Horn Isl, Pellew Group, 22 – 28 Feb.1968, B. Cantrell, UQIC Reg# 53670 – 1-2-3; 3, Howard Springs 24km S Darwin 12 28S 131 03E, 10/11/72, at light, E. Britton, ANIC; 3, Jim Jim Creek 19km WSW Mt Cahill 12 57S 132 33E, 24/10/72, at light, E. Britton, ANIC; 1, Kakadu np, Baroalba Springs 12 48'S 132 49E, 14.11.91, D.V. Wells, NTM; 1, Kakadu np Nourlangie Camp, 17-18/11/79, at light, M. B. Malipatil, NTM; 1, Katherine, 25/1/73, T. Angeles & N. Forresyter, NTM; 4, Lee Point Darwin, 7/3/67, M. S. Upton, ANIC; 1, 4mi SW Lee Point Darwin, 6/3/67, M. S. Upton, ANIC; 2, 15km E by N Mt Cahill 12 49S 132 51E, 29/ 10/72, at light, E. Britton, ANIC; 2, 16km E by N of Mt Cahill, 12 50'S 132 541E, 27/11/74, T. Weir & T. Angeles, NTM; 1, Smith Point. 3.8.82, C. Wilson & S. Collins, NTM; 2, Thorak Reserve via Berrimah, 28/11/74, A. Allwood, ex light trap, NTM.

Queensland. 5, Annan R 3kmW by S Black Mountain 15 41S 145 12E, 26 – 17/4/81, A. Calder, ANIC; 1, Babinda, 9/37, ANIC; 1, Bucasia, K.J. Sandry, 20/2/93, ANIC; 1, Cairns, 12/1/35, ANIC; 2, ditto, 2/50, J. G. Brooks, ANIC; 1, Ditto, NMV; 1, 1km W Cooktown 15 28S 145 15E, 12 – 13/5/81, A. Calder, ANIC; 1, Cairns, 6/1966, A. MacQueen, UQIC Reg# 53727; 1, Edge Hill Cairns, 23 – 24/2/65, at light, J.G. Brooks, ANIC; 1, Ellis Beach 25km NNW Cairns 16 44S 145 39E, 19/5/76, E.B. Britton, ANIC; 4, Cow Bay N of Daintree, Jan-Feb 81, I. C. Cunningham, QPIM; Christmas Creek 15km W of Fairviews via Laura, 26 – 27/6/75, G. B. Monteith, QM; 1, Jardine R. Crossing 29km S Bamiga, 5/9/85, light trap, E. N. Marks, ANIC; 1, Innisfail, 25.12.59, V. Skablum, UQIC Reg# 53721; 1, Iron Range 11 – 17/5/68, G. Monteith, UQIC Reg# 53694; 2, ditto except 16 – 23.11.65, UQIC Reg# 53686/7; 1, Granite Gorge via Marreeba, 21/1/89, R I Storey, at light, QPIM; 1, Iron Range, 26 – 31/10/99, Wood, Dunn & Hasenpusch, QPIM; 1, Jullatten, 18/11/86, Malaise trap, A. Walford-Huggins, QPIM; 1, Lankelly Creek, McIlwraith Rngs. nr. Coen, 28-32/10/69, B. Cantrell, UQIC Reg# 53661; 2, Marina Plains via Musgrave, 17/11/82, Storey, Brown & Jacobson, QPIM; 1, Mossman, 11/1/84, at light, J. D. Brown, QPIM; 1, 1km S Mt Cook 15 30S 145 16E, 13/10/80, T. Weir, ANIC; 1, 2mi. SW Mt Inkerman 19 45S 14730E, 11/12/68, S. Misko, ANIC; 4, 9km ENE Mt Tozer 12 43S 143 17E, 5 – 10/ 7/ 86, T. Weir & A. Calder, ANIC; 3, 11km ENE Mt Tozer 12 43S 143 18E, 11-16/ 7/86, T. Weir & A. Calder, ANIC; 1, 3 km NE Mt Webb 15 03 S 145 09E, 3/5/81, A. Calder, ANIC; 1, 2km NE by E Mt Tozer 12 44S 143 13E, 1/7/86, A. Calder, ANIC; 2, 3km ENE Mt Tozer 12 44S 143

14E, 28/6/86, T. Weir & A. Calder, ANIC; 2, N Queensland, SAMA; 1, 11km WSW Petford, 21/8/1/88, at light, R. Storey, QPIM; 1, 32km S Ravenshoe 17 38S 145 29E, 13/2/66, K Hyde, ANIC; 2, Rocky River 10mi. N.17.2.46, G. Monteith, UQIC Reg# 53653/56; 7, 15km WNW South Johnstone, 10/12/85, at light, Fay & Halfpapp, QPIM; 1, South Johnstone, 12/79, at light, B. Pinese, QPIM; 2, Split Rock 14km S of Laura, 23 – 26/6/75, G. B. Monteith, QM; 1, Yorkeys Knob, 17/8/63, B. V. Timms, UQIC Reg# 53723; 3, 9km SE Yeppoon, 20-30/10/75, I.F.B. Commom, ANIC.

Scirtes exoletus Waterhouse, 1880
(Fig. 10)

Type

Holotype

female, "W Austral" "*Scirtes exoletus* (Type) C. Waterh.", NHM. Seen.

Description (number examined, 59)

Habitus. Length 3.5 – 5.0 mm., relatively flat, oval.

Head. Yellowish, rear and Y-shaped suture often brown; antennae light to dark reddish-yellow, distal portion of each segment lighter. Small, width between eyes about 2.4x dorsal width of eye. Evenly punctate, punctures relative large, each with a moderately sized golden seta. Frons with sides slightly diverging, front edge straight or very weakly concave, edges weakly beaded. Segment 1 of antenna large, curved; segment 2 smaller, barrel-shaped; segment 3 smaller and narrower; segments 4 – 10 long, narrow, cylindrical; segment 11 a little longer than segment 10, all segments setose.

Pronotum. Yellowish with brown pattern. Short, broad. Evenly and moderately to quite strongly punctate, each puncture with a moderately long golden seta. Hind angles obtuse, front edge sinuate, sides weakly beaded.

Scutellum. Yellowish, usually lighter than elytra, slightly longer than wide, lateral sides convex.

Elytron. Yellowish to light reddish-yellow, often a little darker near base and side. Side weakly and narrowly flanged. Moderately to strongly and evenly punctate, each puncture with a yellow seta. Epipleuron relatively wide in front quarter, becoming narrower over rest of elytron, front portion weakly to moderately concave.

Ventral surface. Light reddish-yellow. Pronotal process very narrow between procoxae, apical portion not much wider. Mesosternum with broad, flat, diamond shaped area in midline in front to receive prosternal process; rear tip reaching just reaching front of mesocoxae. Front extension of metasternum in midline, short, widely triangular;

rear midline extension of metasternum about twice as wide as long; approximately equilateral. Metacoxal plate about as long as wide, with anterio-lateral corner extending some way along mesosternum; hind edge straight or slightly convex, sloping towards midline; sides strongly beaded; posteriolateral angles rounded. Metatrochanter small, about 2.0x as long as wide. Metafemur moderately swollen, widest about middle, small notch on hind edge near apex. Dorsal metatibial spine relatively short, about twice size of ventral spine and about half length of segment 1 of metatarsus. Segment 1 of metatarsus a little longer than other segments combined. Ventrites slightly rugose with moderate punctures and fine reticulation, more pronounced towards rear; apex of apical ventrite truncated.

Male

Little external difference between the sexes. Basal piece of penis broad, rounded; trigonium about same length, triangular, apex rounded; single parameroid robust, simple, as long as trigonium (Fig.10). Tegmen about half-length of penis, with broad lobes, not or only slightly separated near apex, partially wrapping around penis, apical edges with short spines (Fig.10).

Notes

A relatively large, flat, distinctive species, recognised by its yellow/grey colour with clear darker mottlings on the pronotum and head and a relatively short metatibial spine. It shares with *S. macroconcolor* and *S. interstinctus* the shallowly grooved elytral epipleura and straight edges to the metacoxal plates, but *S. macroconcolor* is uniformly coloured with a more strongly flanged elytra and *S. interstinctus* has dark stripes on the elytra, flanged elytra, usually stronger and less dense punctures and the hind edges of the metacoxal plates do not slope inwards as they do in *S. exoletus*. The male genitalia of the three species are distinct.

Scirtes exoletus has an unusually wide distribution, occurring in all States except South Australia. I have collected its large dark larvae from submerged leaf litter at the edge of drying pools in the Pilbara and from among emergent vegetation in farm dams in Victoria and northern Tasmania.

Specimens examined

Queensland. 1, Boar Pocket rd. 8km N of Gillies Hwy., 21/2/70, J. G. Brooks, ANIC; 1, Colossus Creek, 10mi. S Miriam Vale, 20/12/66, B. Cantrell, UQIC Reg# 53665; 3, Davies Creek 22km WSW Mareeba, 6/11/84, Storey & Halfpapp, QPIM; 2, Danbulla via Yungaburra, 13/11/92, at light, Storey, De Faveri & Huwer, QPIM; 1, 7km N Hope Vale

Mission, 4/10/80, T. Weir, ANIC; 1, Kenilworth State Forest, 1/4/69, B. Cantrell, UQIC Reg# 53660; 1, 7.5km NNW Kuranda, 20/11/82, Storey & Halfpapp, QPIM; 1, 13km W Kuranda, 7/12/82, J.T. Doyen, ANIC; 1, 8km W Kuranda, 28/12/86, H & A Howden, malaise trap, QPIM; 1, Lake Eacham, 16/12/82, J. T. Doyen, ANIC; 1, Mary Creek 16 33S 145 12E, 5/12/68, at light, Britton & Misko, ANIC; 1, Mt Tambourine, A. M. Lea, SAMA.; 1, 3km ENE Mt Tozer, 28/6/86, D. H. Colless, malaise trap, ANIC; 1, 7km NE Tolga, 2/87, Storey, & De Faveri, QPIM; 2, Whitfield rd. 22km from Cairns, 21/10/71, J. G. Brooks, ANIC. **New South Wales.** 2, Collector, 2/61, C. Watts, SAMA; 1, Epping, 4/3/87, malaise trap, I. Buddie, ANIC; 1, Harrington, 8/9/83, G. Williams, ANIC; Tooloom Plateau Via Woodenbong, 30 – 31/12/66, G. Monteith, UQIC Reg# 53714; 1, Wingham Scrub 31 52S 152 22E, at light, 3/1/70, Britton, Holloway & Misko, ANIC. **Northern Territory.** 1, McArthur River 16,47S 135 45E 14km S by W Cape Crawford, 25/10/75, M. S. Upton, ANIC; 1, Ditto, 6/11/73, ANIC; 1, Nourlangie Creek 8km E of Mt Cahill, 7/5/75, A. Allwood & T. Angeles, NTM. **Tasmania.** 4, 4 km W Port Latta, 27/11/00, C. Watts, SAMA. **Victoria.** 8, Healsville, 12/68, C. Watts, SAMA; 1, Thomson River Bells clearing, 8 March 1970, MV light, NMV; 2, Tullamarine, 4/9/75, SAMA; 1, 2 km E Warburton, 14/1/97, C. Watts. SAMA. **Western Australia.** 3, Crossing Pool Millstream 21 35S 117 04E, E. B. Britton, ANIC; 1, Deep Reach Millstream 21 35S 117 04E, at light, E. B. Britton, ANIC; 1, Millstream Fitzroy Crossing area, 17/3/83, K. & E. Carnaby, ANIC; 5, Hammersly Range, W. D. Dodd, SAMA; 9, ditto, at light, 30/10/70, E. Britton, ANIC; 5, Millstream, Coll Ranger, Summer 2000, SAMA; 2, 1 km N Millstream, 1 – 4/71, M. S. Upton, ANIC.

Scirtes interstinctus sp. nov.

(Fig. 11)

Types

Holotype

male: "15.30S 145.16E 5 km SEbyS Cooktown QLD 19 May 1977". F.B. Common & E.D. Edwards", ANIC.

Paratypes

12; 4, "Dividing Range 15 km W of Captain Billy Creek Cape York Pen, N.Qld. 142 45E 11 40S 4-9 vii. 1975 G. B. Monteith", QM; 1, "AUSTRALIA n QLD Davies Ck 22 km WSW of Mareeba Malaise T 2. xii. 1984 Storey & Titmarsh", QPIM; 1, Ditto, 2. x.-6 xi 1984 Storey & Halfpapp", QPIM; 1, Ditto "2 xii – 21.xii 1984 Storey & Brown", QPIM; 1, "15.14S 145, 07E 7 Km N of Hope Vale Mission QLD 4 Oct 1980 T. Weir", ANIC; 1, "8 Km W

Kuranda NQ 28 Dec.1986 H & A Howden Malaise trap", ANIC; 1, "12.44S 143.14E 3 K ENE Mt Tozer 28 June – 4 July 1986 D. H. Colless Malaise trap", ANIC; 1, "NEQ 17 19S 145 37E Pecramon Scrub 750m 9 Dec 1995 G. Monteith Pyrethrum trees", QM.

Description (number examined, 13)

Habitus. Length 3.8 – 4.7 mm., relatively flat, oval.

Head. Reddish-yellow with darker markings; antenna reddish-yellow. Small, width between eyes about 2.5x dorsal width of eye. Evenly punctate, punctures relative large, each with a moderate sized golden seta. Frons with sides slightly diverging, front edge straight or very weakly concave, edges weakly beaded. Segment 1 of antenna large, curved; segment 2 smaller, barrel-shaped; segment 3 smaller and narrower; segments 4 – 10 long, narrow, cylindrical; segment 11 about same length as segment 10, all segments setose.

Pronotum. Light reddish-yellow with dark brown pattern. Short, broad. Punctures large, relatively shallow, moderately dense, each puncture with a moderately long golden seta. Hind angles obtuse, front edge sinuate, sides weakly beaded.

Scutellum. Yellowish, usually lighter than elytra, slightly wider than long, lateral sides convex.

Elytron. Light reddish-yellow, with darker stripes sutural region narrowly yellow. Side moderately to quite strongly flanged in front half; evenly punctate with relatively large shallow punctures, each puncture with a yellow seta. Epipleuron relatively wide in front quarter becoming narrower over rest of elytron, front portion weakly to moderately concave.

Ventral surface. Light reddish-yellow. Pronotal process very narrow between procoxae, apical portion not much wider. Mesosternum with broad, flat, diamond shaped area in midline in front to receive prosternal process; rear tip reaching past front of mesocoxae. Front extension of metasternum in midline, short, widely triangular; rear midline extension of metasternum about twice as wide as long. Metacoxal plate about as long as wide, with anteriolateral corner extending some way along metasternum; hind edge slightly sinuate; sides beaded; posteriolateral angles rounded. Metatrochanter small, elongate, about 2.5x as long as wide. Metafemur moderately swollen, widest about middle, small notch on hind edge near apex. Dorsal metatibial spine about twice size of ventral spine and about half-length of segment 1 of metatarsus. Segment 1 of metatarsus a little longer than other segments combined. Ventrites slightly rugose with moderate punctures and fine reticulation, more pronounced towards rear; apex of apical ventrite truncated.

Male

Little external difference between the sexes. Basal piece of penis short, broad, rounded; trigonium about twice as long as broad, spatulate with raised ridge at base; single parameroid robust, a little longer than half length of trigonium, apex hooked (Fig. 11). Tegmen shorter than penis, lobes short, slightly asymmetrical, apical edges with short spines, strongly wrapped around penis (Fig. 11).

Variation

The extent of the brown stripes on the elytra is variable; in some they are reduced to the base and some scattered markings elsewhere on elytra. The colour of the antennal segments varies from nearly uniform yellowish to quite dark with much lighter distal portions.

Etymology

Latin. "Interstinctus" – variegated, a reference to the dorsal colour.

Notes

A relatively large species recognised by its distinct darker mottlings on the pronotum and head and short linear markings on the elytra, relatively large shallow punctures and flanged elytra. It shares with *S. exoletus* the shallowly grooved elytral epipleurae, patterned head and pronotum and straight edges to the metacoxal plates but has linear markings on the elytra, more strongly flanged elytra, generally larger punctures and quite different male genitalia.

Most specimens have been captured in Malaise traps, none at light, which is a different pattern than other *Scirtes* which may indicate a somewhat different natural history.

Scirtes kaytae sp. nov.

(Fig. 12)

Types

Holotype

male, "Qld. Bushland Beach 20km N Townsville A. J. Watts 15 – 20/3/98", SAMA.

Paratypes

37; 21, "Qld. Bushland Beach 20km N Townsville A. J. Watts 23 – 30/12/97", SAMA; 10, ditto, "at light 16 – 18 Jan 1998", SAMA; 3, ditto 6 – 11/98, SAMA; 2, ditto, 26-29 Feb 1998, SAMA; 1, ditto, 28/3/98, SAMA.

Description (number examined, 249)

Habitus. Length 3.9 – 5.5 mm., relatively flat, oval.

Head. Reddish-yellow. Small, width between eyes about 3x dorsal width of eye. Strongly, densely and

evenly punctate. Frons with front angles bulging outwards, front edge straight or very weakly concave, front bent upwards, edge beaded. Segment 1 of antenna large, barrel-shaped; segment 2 about half as long, oval; segment 3 as long as second but narrower; segments 4 – 10 long, narrow, tending to be more expanded on front edge, particularly central ones; segment 11 and segment 10 subequal.

Pronotum. Reddish-yellow; short, broad. Evenly and quite densely punctate, punctures confluent at sides, each with a long golden seta. Hind angles obtuse, front edge strongly sinuate, sides weakly beaded.

Scutellum. Reddish-yellow; about as long as wide, lateral sides weakly convex.

Elytron. Reddish-yellow with diffuse darker areas towards sides and front. Quite strongly and evenly punctate, each puncture with a yellow seta although often abraded off. Weakly flanged towards front. Epipleuron yellow, relatively wide in front quarter, evenly becoming much narrower over rest of elytron.

Ventral surface. Reddish-yellow, often with diffuse darker areas. Pronotal process very narrow between procoxae, apical portion not much wider, strongly keeled. Mesosternum with narrowly elongate groove for reception of pronotal process; tip reaching to level of mesocoxae. Rear triangular midline extension of metasternum approximately same size as front extension; about twice as wide as long, edge beaded. Metacoxal plate broader than long with anteriolateral corner extending some way along metasternum; hind edge strongly concave; sides beaded; posterior-lateral angles rounded. Metatrochanter very small, apex pointed. Metafemur greatly swollen, widest just before middle, quite strongly indented on hind edge near apex. Dorsal metatibial spine relatively long more than twice size of ventral spine and about two thirds length of segment 1 of metatarsus. Segment 1 of metatarsus a little longer than other segments combined. Ventrites with punctures small, shallow; reticulation moderate fine, more pronounced towards rear; apex of apical ventrite truncated or concave.

Male

Basal piece of penis elongate oval; trigonium about as long as basal piece, a small sharp hook at apex; single parameroid a little shorter than trigonium, narrow, slightly curved towards tip which is sharply pointed (Fig. 12). Tegmen about as long as penis, lobes narrow, well separated, with row of quite strong spines on outside edge (Fig. 12). Front of frons more strongly upturned; antenna stouter with expansions on inside of antennal segments greater than in female.

Variation

There is considerable variation in the strength of the colour pattern on the elytra from almost uniformly reddish-yellow to reddish yellow with almost black markings on shoulders and each elytron with a broad dark stripe near but not quite reaching the sides. The strength of the shovel-like upturned frons of the male (and weakly in some females) is quite variable as are the internal expansions of the antennal segments.

Etymology

Named after my granddaughter Kayt whose father collected many of the specimens.

Notes

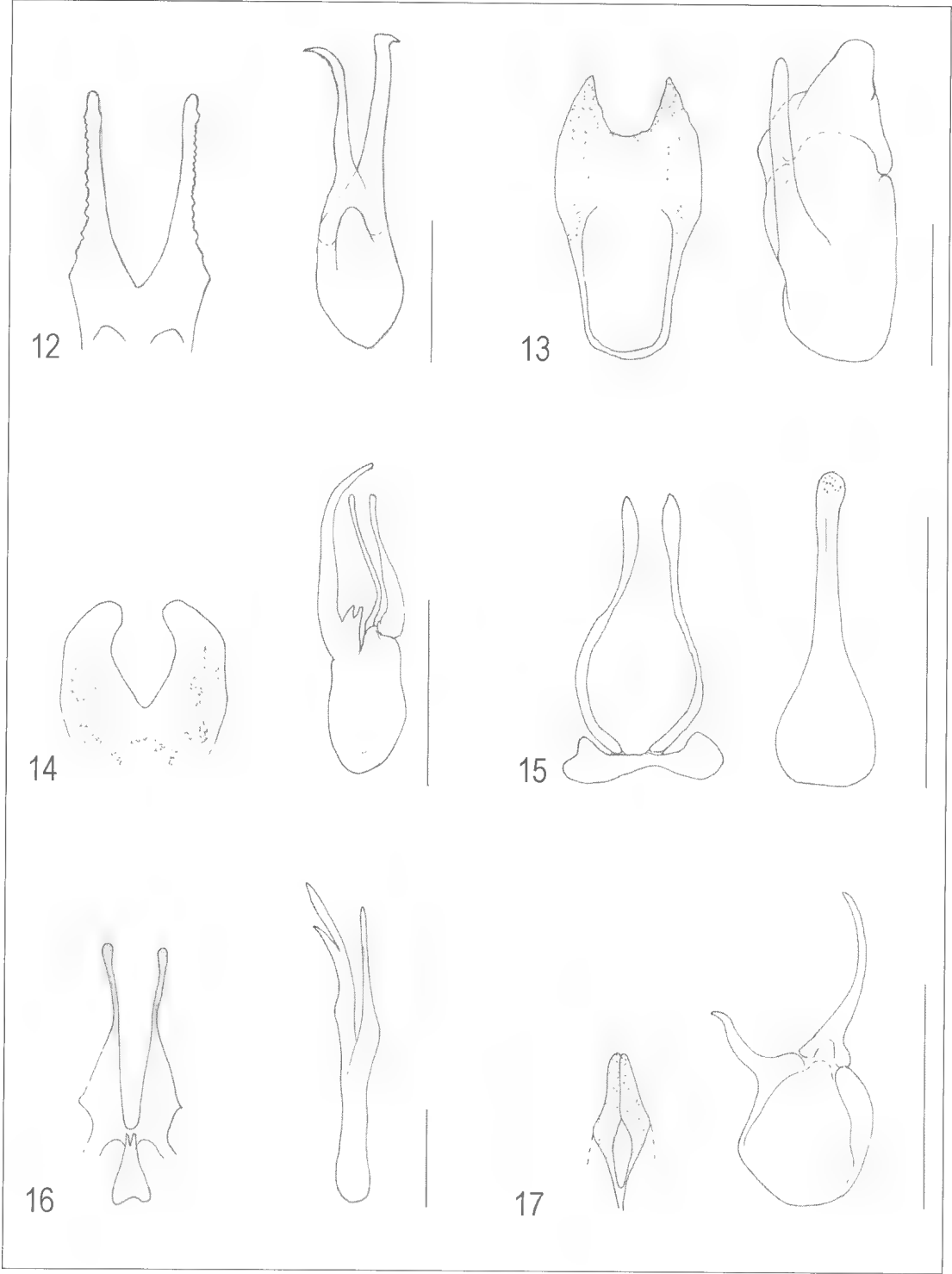
A large, common species in tropical north and eastern Australia, reddish but usually with noticeably darker areas on the elytra. The males are very distinctive with stout antennae with the inner portions of the individual segments enlarged slightly on the insides and frons with front edge projecting forwards and upwards. These characters are much less obvious in the females. The male genitalia are distinctive for the spines on the outer margin of the tegmen and hooked tip to the penis which is often visible in preserved specimens.

Broadly sympatric with the two other large reddish-yellow oval species with concave hind margins to the metacoxal plates, *S. emmae* and *S. tindaleensis*. Both of these are more uniform in colour without the lateral darker markings on the elytra and lack the asymmetric antennal segments and the upturned frons of *S. kayt* as well as clear differences in the male genitalia. Could also be confused with the rarer *S. ruforotundus*, a more rounded, dark reddish species, often with the disc of the elytra lighter and with normal frons and thin antennae. The male genitalia of *S. ruforotundus* are very different, and never protrude from the abdomen.

The large black larvae occur among emergent vegetation in seasonal swamps.

Specimens examined

Queensland. 1, Archers Creek Mt Garnet Rd., 28/12/64, J. G. Brooks, ANIC; 1, Ayr 19 35S 147 24E, 30/11/70, W. B. Muir, ANIC; 1, Big Mitchell Ck. Mareeba-Molloy Road, 4/5/67, D. H. Colless, ANIC; 1, Bundaberg 24 51S 152 21E, 14/3/72, Frauca, ANIC; 1, Bundaberg, 20/2/72, H. Frauca, ANIC; 22, ditto, 14/4/63, C. Watts, SAMA; 1, Bundaberg, SAMA; 5, ditto, 25 – 26/ 3/ 84, K. H. Halfpapp, at light, QPIM; 5, Cairns, 2/50, G. Brooks, ANIC; 1, Calliope River 23km SE Gladstone 23 50S 152 13E, 23/1/70, light trap, S. Misko, ANIC; 2, Cape Pallarenda 19 14S 146 46E, 14 – 17/1/74, at light, R. A. Barrett, ANIC; 1, Carr Creek 18km NNW



Figs 12-17. Dorsal views of tegmen (left) and penis (right). Lines = 0.5 mm. 12. *Scirtes kaytae* sp. nov. 13. *S. macroconcolor* sp. nov. 14. *S. microrotundus* sp. nov. 15. *S. ruforotundus* sp. nov. 16. *S. tindaleensis* sp. nov. 17. *S. alastairi* sp. nov.

Mareeba, 21/5/80, I.D. Nauman, ANIC; 10, Cemetery Point Veron via Maryborough, 24/12/70, I. F. B. Common, ANIC; 4, Gordonvale, 1/15/99, A. Podlussany, HUNG; 1, Gin Gin, 2/4/62, C. Watts, SAMA; 5, Giru, 18/4/81, B.B. Lowery, at light, ANIC; 1, Kalpower Crossing 75km NW Laura, 2/4/83, at light, R. I. Storey, QPIM; 1; 1, 70km SW Greenvale, at light, 1-10/ 3/95, A. J. Watts, SAMA; 1, Mango Island off Millaroo, 13/3/74, J. H. Barrett, QPIM; 5, Marina Plains via Musgrave, 10/5/83, Storey & Brown, QPIM; 2, N Queensland, Blackburn Coll, SAMA; 22, 30km N Marlborough, at light, 24/11/81 Hangay, Herozeg & Vojnite, HUNG; 1, Mossman, 8/1/84, J. Brown, at light, QPIM; 6, Normanton, 4/5/63, at light, P. F. Aitkin & N.B. Tindale, SAMA; 2, Old Laura Station 28km N Laura, 3/4/83, at light, R.I. Storey, QPIM; 2, Ingham, 16/2/60, K. I. Harley, ANIC; 5, ditto, 6/3/84, K. H. Halpapp, at light, QPIM; 1, ditto, SAMA; 1, Iron Range, 5/71, J. Brooks, ANIC; 16, Lansdown Station 7km S of Woodstock 19 40S 146 51E, 16.1.74, at light, RABarrett, ANIC; 2, Pistol Gap Byfield 22 50S 150 40E, 10/1/70, at light, Britton Holloway & Misko, dry sclerophyll, ANIC; 3, 2km S Ravenshoe 17 38S 145 2E, 13/2/66, K. Hyde, ANIC; 1, Tolga, 2 – 3/80, N. Gough & J. D. Brown, QPIM; 2, 7km N Tolga, 3/88, Storey & De Favers, QPIM; 1, ditto, 1/88, QPIM; 5, Townsville, F.H. Taylor, ANIC; 4, ditto, 12/3/58, K. L. Harley, ANIC; 9, ditto, 1/16/68, P. Ferrar, ANIC; 2, Stuart Range, 1 – 2/27, Hale & Tindale, SAMA; 1, Waterfall Creek 20ml N. of Rollingstone, 29.3.73, A. Allwood & T. Angeles, NTM; 2, Woodstock, 3/54, A. J. Brooks, ANIC; 1, Yeppoon, 14 – 18/12/64, I. F. Common & M. S. Upton, ANIC; 1, Yeppoon, 30/1/70, I. F.B. Common, ANIC.

Northern Territory. 7, Bessie Springs 8km ESE Cape Crawford 16 40S 135 51 E, 12/4/76, at light, J. E. Feehan, ANIC; 7, Batten Point 30km NE by E Borrooloola 15 54S 136 32E, at light, 18/4/76, J. E. Feehan, ANIC; 1, 22km WSW Borrooloola, 16/4/76, at light, J.E. Feehan, ANIC; 1, Edge Hill, 4/64, J Brooks, ANIC; 1, Cahills Crossing East Alligator River 12 26S 132 58E, 29/5/73, at light, E. G. Matthews, ANIC; 1, 5km NNW Cahills Crossing East Alligator river 12 23S 132 57E, 28/5/73, E. G. Matthews, ANIC; 1, Darwin River 16km SW by S of Noonamah 12 44S 130 58E, 16/5/74, T. Angeles & W. Mollah, NTM; 2, Jasper Gorge 54km NW of Victoria River Downs 16 02S 130 41E, 30.4.74, T. Weir & T. Angeles, NTM; 1, 10km SW Jabiru, 29/1/99, C. Watts, SAMA; 3, Katherine, at light, 6 – 10/2/68, J. A. L. Watson ANIC; 1, Katherine, 23/1/71, T. Weir & A. Allwood, NTM; 2, Koongarra 12 52S 132 50E, 6 – 10/3/73, M. S. Upton, ANIC; 1, Lee Point Darwin, 8/3/67, M. S.Upton, ANIC; 1, Melville Isl., at light, 4/2/68, Matthews, ANIC;

5, McArthur River 14km SW Cape Crawford 16 47S 135 45E, 11/4/76, J. E. Feehan, ANIC; 2, Magela Creek 1km NNW Mudginberry HS 12 36S 132 52E, 25/5/73, Matthews & Upton, ANIC; 2, McArthur River 14km SW of Cape Crawford 16 47S 135 45E, 11/4/76, J. F. Feehan, ANIC; 1, October Creek on Borrooloola Road, 7/4/76, T. Weir, NTM; 3, Roper River, 6/4/76, T. Weir, NTM; 1, Smith Point, 23/2/81, A. Allwood, NTM; 1, Tortilla flats, 3.3.82, J. Waldock, NTM; 1, Tindale 14 31S 132 22E, 20/12/67, W. J. M. Vestjens, ANIC; U.A.R. 21/2/67, C.S.Li, NTM; 1, Victoria River crossing 15 36S 131 07E, 29/4/74, T. Weir & T. Angeles, NTM; 1, Wildman River Cashew project, 3/1/89, Malipatil & Houston, QPIM.

Western Australia. 2, 8km S Cape Bertholet West Kimberley 17 19S 122 10E, 21/4/77, D. H. Colless, ANIC; 5, 3km S Coulomb Pt. West Kimberley 17 32 122 09E, 20/4/77, D. H. Colless, ANIC; 2, Fitzroy River, 11/4/84, at light, K. & E. Carnaby, ANIC; Kununurra, 27/12/82, R. I. Storey, QPIM; 6, Kununurra, 17-21/ 2/ 68, E. Matthews, ANIC; 1, 6km W Martin's Well West Kimberley 16.08S 122 48E, 25/4/77, D. H. Colless, ANIC; 3, Ord River Valley Kimberley Res. Station, 9/3/82, E.S.C. Smith, ANIC.

Scirtes macroconcolor sp. nov.

(Fig.13)

Types

Holotype

male; "14 49S 126 49E Carson escarpment W.A. 9 – 15 Aug.1975 I. F. Common and M.S. Upton", ANIC.

Paratypes

7; 1 slide, as for holotype, SAMA; 1, "Bessie Springs 16 40S 135 51E 8 km ESE Cape Crawford NT. 26 Oct. 1975 M. S. Upton", ANIC; 1, "nr. Katherine, NT 21 May 1992 P. S. Cranston & P. J. Gullan coll.", ANIC; 1, "15 02S 126 55E Drysdale River, W.A. 3 – 8 Aug.1975 I. F. B. Common and M. S. Upton", ANIC; 3, "N.T. U.D.P. Falls 18 – 19 Jul 1980 M.V. Light M.B. Malipatil" NTM.

Description (number examined, 8)

Habitus. Length 4.5 – 4.8 mm., relatively flat, oval.

Head. Light reddish-yellow. Eyes large, width between eyes about 2.3x dorsal width of eye. Moderately and evenly punctate. Frons with sides moderately diverging, front edge weakly concave, front corners slightly downturned, edges weakly beaded. Segment 1 of antenna large, barrel-shaped; segment 2 about two-thirds length of segment 1, oval; segment 3 about half length of segment 2,

narrower; segments 4 - 10 long, relatively wide, parallel sided, becoming progressively flatter; segment 11 about same size as segment 10.

Pronotum. Light reddish-yellow. Short, broad. Evenly and moderately to quite strongly punctate, each puncture with a moderately long golden seta. Hind angles obtuse, front edge strongly sinuate, sides weakly beaded.

Scutellum. Light reddish-yellow. A little longer than wide, lateral sides convex.

Elytron. Light reddish-yellow to reddish-yellow, sutural region narrowly lighter. Sides quite broadly flanged, more strongly in middle. Moderately to strongly and evenly punctate, each puncture with a short yellow seta. Epipleuron relatively wide in front quarter becoming narrower over rest of elytron, front portion shallowly grooved.

Ventral surface. Uniformly light reddish-yellow. Pronotal process very narrow between procoxae, apical portion a little wider. Mesosternum with diamond shaped groove in midline in front for reception of pronotal process; rear tip reaching just to front of mesocoxae. Front extension of metasternum in midline, small, short, triangular bordered behind; rear midline extension of metasternum about as wide as long; approximately equilateral, tip reaching to about middle of metacoxal plate. Metacoxal plate about as wide as long, with antero-lateral corner extending some way along metasternum; hind edge straight, sloping slightly to midline; sides very weakly beaded; posteriolateral angles rounded. Metatrochanter small about 2.0x as long as wide. Metafemur greatly swollen, widest about middle, small notch on hind edge near apex. Dorsal metatibial spine about twice size of ventral spine and about two-thirds length of segment 1 of metatarsus. Segment 1 of metatarsus a little longer than other segments combined. Ventrites slightly rugose, moderately punctate, reticulation fine, more pronounced towards rear; apex of apical ventrite truncated.

Male

Little external difference between sexes. Basal piece of penis large, oval; trigonium shorter, squatly triangular, apex rounded; parameroid large, thumb-like, broad in lateral view, narrow in dorsal view (Fig. 13). Tegmen a bit shorter than penis, lobes short, conical, well separated (Fig. 13).

Variation

Some specimens have diffuse darker areas on the elytra and vague darker patterning on the pronotum.

Etymology

Latin. "Macro" - large; "concolor" - uniform colour.

Notes

A moderately sized species with uniform colour. straight hind edges to the metacoxal plates, weakly grooved epipleuron and a noticeably flanged elytra.

Scirtes microrotundus sp. nov.

(Fig. 14)

Types

Holotype

Male; "Mossman Gorge, N. Qld. 23 Apr. 1967 D. H. Colless", ANIC.

Paratypes

3 slides, as for holotype, 2 ANIC, 1 SAMA.

Description (number examined, 4)

Habitus. Length 2.0 mm., flat, round.

Head. Dark brown. Small, width between eyes about 2.7 x dorsal width of eye. Moderately and evenly punctate, each puncture with a moderate sized pale seta. Frons with sides strongly diverging, front edge concave, edges beaded. Antenna reddish-yellow, lighter towards base; segment 1 of antenna large, barrel-shaped; segment 2, barrel-shaped about three quarters size of segment 1 in both width and length; segment 3 smaller about two thirds length of segment 2 and narrower; segments 4 - 10 long, cylindrical; becoming a little flatter apically, segment 11 a little longer than segment 10.

Pronotum. Dark chestnut, extreme margins lighter. Short, broad. Evenly and moderately punctate, each puncture with a moderately long golden seta. Front angles weakly extended; hind angles obtuse; sides weakly beaded, weakly upturned.

Scutellum. Dark reddish-yellow; sides broad, slightly wider than long, lateral sides weakly convex.

Elytron. Dark reddish-yellow. Sides weakly flanged towards front. Moderately to strongly and evenly punctate, each puncture with a short yellow seta. Epipleuron relatively wide in front quarter becoming narrower over rest of elytron, front portion widely and shallowly grooved.

Ventral surface. Dark reddish-yellow, appendages tending lighter. Pronotal process very narrow. Mesosternum with short, shallow, relatively broad, triangular groove for reception of pronotal process; tip just reaching to level of mesocoxae. Front extension of metasternum relatively small, broadly triangular, rear midline extension of mesosternum relatively long, about 1.5x as wide as long. Metacoxal plate wider than long, with antero-lateral corner extending some way along metasternum; hind edge straight or weakly sinuate, sloping towards midline; midline of coxae short, shorter than length of metasternal extension; sides beaded; posteriolateral angles rounded. Metatrochanter

small, elongate, about 2.4x as long as wide. Metafemur moderately swollen, widest about middle. Dorsal metatibial spine moderately long about twice size of ventral spine and about two-thirds length of segment 1 of metatarsus. Segment 1 of metatarsus a little longer than other segments combined. Ventrites with punctures small, shallow; reticulation moderate, fine, more pronounced towards rear; apex of apical ventrite truncated or weakly concave.

Male

Only males known. Basal piece of penis, oval; trigonium formed of two long thin pieces one broader than the other; single parameroid longer and thinner than trigonium lobes, apex pointed, small bifid structure near its base (Fig. 14). Tegmen about half length of penis, lobes broad, well separated (Fig. 14).

Variation

Little variation in the four known specimens.

Etymology

Greek. "Mikros" – small. Latin "rotundus" – round.

Notes

A small dark, almost round species with short metacoxal plates, weakly concave epipleura and distinctive male genitalia.

Scirtes ruforotundus sp. nov.

(Figs 2, 15)

Types

Holotype

male, "15.30S 145 16E 1 km SE of Mt Cook Qld 13 Oct. 1980 T. Weir", ANIC.

Paratypes

28; 1, "Brandy Cr 8 mi. NE Proserpine Q (20 20S 148 41E) 1.xii.1968 at light Britton & Misko", ANIC; 1, 'Cairns 5/49 J. G. Brooks', ANIC; 1, '16 03S to 16.05S QLD145 28E Cape Tribulation 21 – 28/3/84 A. Calder & T. Weir', ANIC; 1 slide, Cape Tribulation NQ 14 – 17 Jul. 1982 S & J Peck coll, SAMA; 1, "Cardstone Qld 20/11/66 K. Hyde", ANIC; 1, "Cooper Creek, 18ml. N. of Daintree River, N. Qld. 21 – 22.vi.1969 G.B.Monteith" "UQIC Reg# 53713", UQIC; 1, "Crystal Ck. Q., 23 mi. SSE Ingham 19 58S 146 16E, 9/12/68 at light Britton & Misko", ANIC; 2, "Gap Ck., 6ml. N of Bloomfield R. N. Qld. 13.xi. 1965 G. Monteith" "UQIC Reg# 53643/4". UQIC; 1, "15 12S 143 52E Hann R. 73 km NW by W Laura Qld. 27 June 1986 T. Weir & A. Calder", ANIC; 3, "15 16S 144 59E 14 km W by N of Hope Vale Mission Qld. 8 – 10 Oct

1980 T. Weir", ANIC; 1, "15.14S 145. 07 E 7 km N of Hope Vale Mission Qld. 4 Oct 1980 T. Weir", ANIC; 1, "Iron Range Cape York Pen. N. Qld. 11 – 17 May 1968 G. Monteith" "UQIC Reg# 53693", UQIC; 2, "Iron Range Cape York Pen. N. Qld. 16 – 23.xii.1965 G. Monteith" "UQIC Reg# 53690/1". UQIC; 1, "Mackay", SAMA; 1, "Mitchell River Settlement, Qld. 4 iv.70 A. L. Dyce (From large open cavity 6' above ground level in mango tree)" ANIC; 2, "9 km SW Madang PNG 1.ii.1988 bamboo internode B 18 R. Kitching", ANIC; 1, "W of KOWI Madang PMG 3.ii.1989 TH24/R Kitching", ANIC; 3, "Miller's Crossing, 30mls N. of Cooktown N.Qld. 24-25.xi.1965. G. Monteith" UQIC Reg# 5384/4/5"; 2, "15 30S 145 16E 1 km SE Mt Cook Qld 13 Oct 1980, T. Weir", SAMA; 1, "N. Queensland", SAMA; 3, "15 05S 145 07E Mt Webb Nat Pk. QLD 28 – 30 Sept 1980 T. Weir", ANIC; 1, "12 44S 143 14E 3 km ENE Mt Tozer 28 Jun – 4 Jul. 1986, T. Weir & A. Calder" ANIC; 1, "15.03S 145. 09E 3 km NE of Mt Webb QLD, 1 3 Oct 1980 T. Weir", ANIC; 1, "Silver Plains Homestead Cape York Pen. Q 24 Dec.1962 J. L. Wassell", ANIC; 1, "AUSTRALIA. n Qld.15 km NW of South Johnstone light trap 17. x. 1986, Fay & Halpapp, "QPIM; 1," "The Boulders" via Babinda, N. Qld 15.xi.1969 B. Cantrell.", "UQIC Reg# 53669", UQIC; 1, "Upper Mulgrave River N. Qld. 1-3.xii.1965. Cent Qld. B. Cantrell", "UQIC Reg# 53665", UQIC.

Description (number examined, 29)

Habitus. Length 3.2 – 4.7 mm., relatively flat, broadly oval.

Head. Dark reddish-yellow to nearly black, antenna light reddish-yellow to reddish-yellow. Small, width between eyes 2.2x dorsal width of eye. Moderately and evenly punctate. Frons with sides concave, front edge quite strongly concave, edges beaded. Segment 1 of antenna large, barrel-shaped; segment 2 smaller, cylindrical; segment 3 shorter, narrower; segments 4 – 10 long, relatively broad, front edge slightly concave, segment four longest; segment 11 a little longer than segment 10.

Pronotum. Dark reddish- yellow to nearly black. Short, broad. Evenly and moderately densely punctate, each puncture with a moderately long golden seta. Hind angles obtuse, front edge sinuate, sides beaded.

Scutellum. Dark reddish-yellow. Sides approximately equal length, lateral two weakly convex. Strongly and evenly punctate.

Elytron. Dark reddish-yellow, disc tending lighter. Side narrowly flanged. Moderately and evenly punctate, each puncture with a short yellow seta. Epipleuron relatively wide in front gradually narrowing to near apex, front portion weakly and shallowly grooved.

Ventral surface. Light reddish-yellow to reddish-yellow. Pronotal process very narrow between procoxae, apical portion not much wider, strongly keeled. Mesosternum with narrow, triangular groove for reception of pronotal process; tip reaching past level of front of mesocoxae. Rear triangular midline extension of metasternum as long as wide; front extension about twice as wide as long sometimes semicircular rather than triangular. Metacoxal plate about twice as wide as long, with anterio-lateral corner extending some way along metasternum; hind edge moderately concave; sides weakly beaded; posteriolateral angles rounded. Metatrochanter small, almost twice as long as wide. Metafemur greatly swollen, widest just before middle, with small notch on hind edge near base; reddish-yellow often darker on outside edge. Dorsal metatibial spine relatively long, broad, about twice size of ventral spine and approximately length of segment 1 of metatarsus. Segment 1 of metatarsus a little longer than other segments combined.

Male

Tergite 7 broadly triangular, with apodemes, with rectangular apical process (Fig. 2g). Penis very small, simple, not divided into basal piece and trigonium, elongate, tip rounded, without parameroids (Fig. 15). Tegmen about as long as penis, with wide transverse basal bit, lobes thin, sinuate, bulbous at tips (Fig. 15).

Variation

The colour is darker in some and the contrast between the lighter disc of the elytra and the darker sides is variable. The hind edge of the metacoxal plate varies from weakly to quite strongly concave. The relative lengths of the tegmen and penis vary a bit.

Etymology

Latin. "Rufus" – red, "rotundus" – round.

Notes

A relatively rare, moderately sized, shiny, dark reddish species readily recognised by its broadly oval, almost rounded, shape, weakly to moderately convex hind edges of the metacoxal plates, weakly grooved front portions of the elytral epipleura, long metatibial spine and the 7th tergite in the males with a pronounced apical process unique in Australian *Scirtes*. The male genitalia are unlike any other Australian *Scirtes* in having a small, weak, penis much shorter than the tegmen.

The species is widespread in north Queensland and is also known from Madang on the north coast of New Guinea. The only habitat records are one from a tree hollow and one from bamboo internodes

suggesting that the species may breed in such situations.

Scirtes tindaleensis sp. nov.

(Figs 1, 16)

Types

Holotype

male, "Qld. Greenvale 70km SW at light 14 – 24 Mar 1995 A. J. Watts", SAMA.

Paratypes

65; 2, "NT. Kakadu NP c.1km S of Arnhem Hwy on Pine Creek Rd. M.V. Light 25 – 30 Mar. 1980 M. B. Malipatil", NTM; 52, "Tindale, N.T. 14.31S 132.22E 1 – 20 Dec.1967 light trap W. J. M. Vestjens", 47, ANIC, 5 NMV, 2 slides SAMA; 1, "Burrell's Ck Stuart H'way, N.T. 25 Nov. 1972 D.H.Collins", ANIC; 1, "Valley of lagoons via Arenvale Apr. 1988 n. Qld. K. H. Halfpapp", QPIM; 1 "Iron Range Cape York Pen. N. Qld. 1-4.v.1973 G. B. Monteith", QM; 1, "Captain Billy Creek Cape York Pen, N, Qld.142 50E 11 40S 9-13 vii.1975 G. B. Monteith", QM; 1, "3 mi S of Marmor, Q. 29 mi SSW of Rockhampton 23.43.5S 150, 42E 13 xii.1968. at light Britton & Misko", ANIC; 2, "NT Lake Bennett area c 25km SE of Manton Dam 25 – 30 Dec 1979 M. B. Malipatil" NTM; 11, "U.A.R. N.T. Feb.21.1967 Coll. C.S.Li", NTM.

Description (number examined, 66)

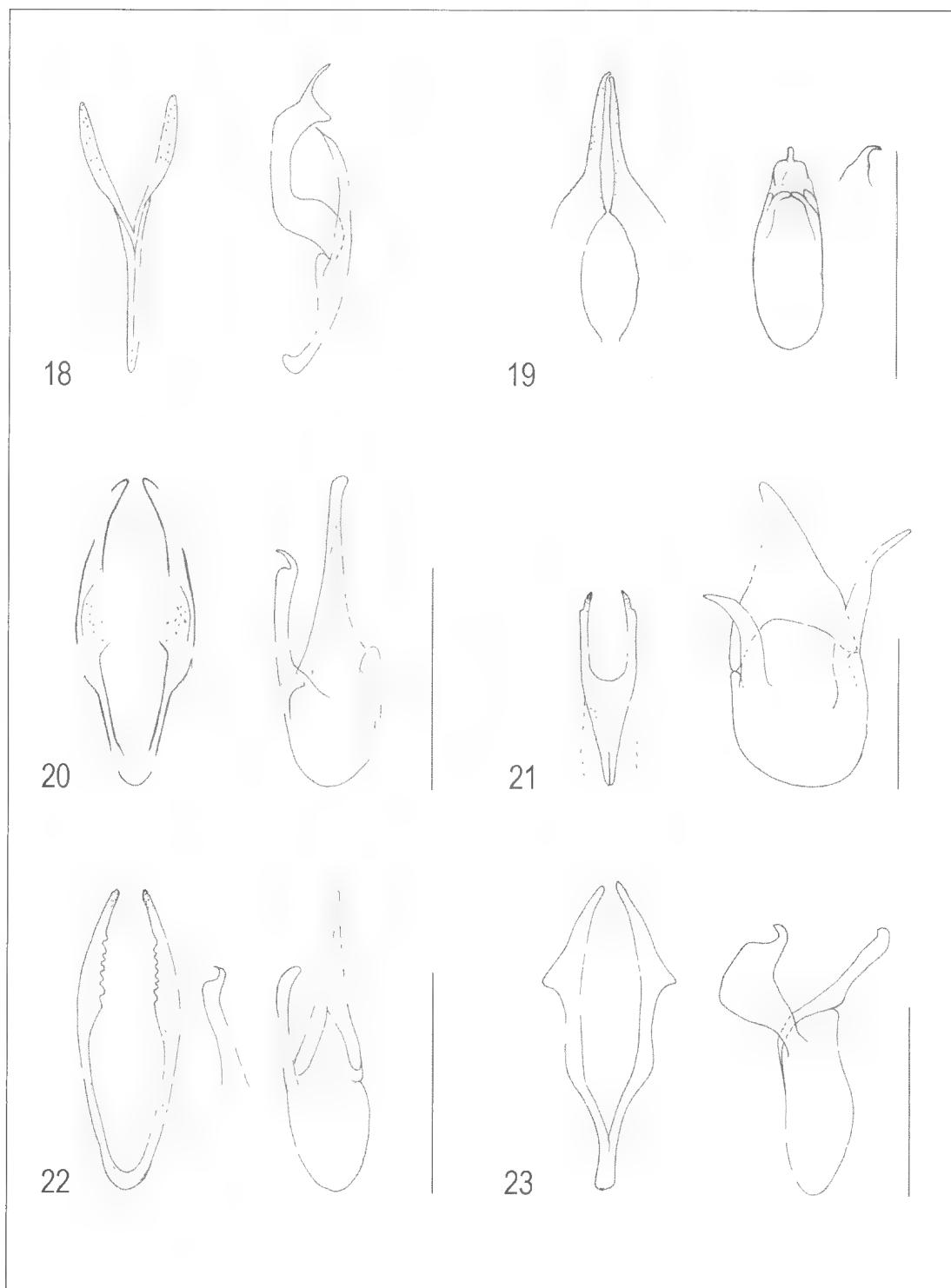
Habitus. Length 3.5 – 4.9 mm., relatively flat, oval.

Head. Reddish-yellow to dark reddish yellow; antennae light reddish-yellow. Relatively small; width between eyes about 2.5x dorsal width of eye. Strongly, quite densely and evenly punctate. Frons with sides diverging, front edge straight or weakly concave, edges beaded. Segment 1 of antenna large, barrel-shaped; segment 2 smaller, cylindrical, segment 3 as long as segment 2 but narrower; segments 4-10 long, narrow, cylindrical; segment 11 approximately the same length as segment 10.

Pronotum. Reddish-yellow to dark reddish-yellow. Short, broad. Evenly and moderately punctate, each puncture with a moderately long golden seta. Hind angles obtuse, anteriolateral angles projected forward, sides weakly beaded.

Scutellum. Reddish-yellow to dark reddish yellow. Sides approximately equal length, lateral two convex.

Elytron. Reddish-yellow to dark reddish-yellow, with diffuse darker areas. Sides subparallel, weakly and narrowly flanged, more strongly towards front. Moderately and evenly punctate, each puncture with a short yellow seta. Epipleuron relatively wide at front, evenly narrowing to near base.



Figs 18-23. Dorsal views of tegmen (left) and penis (right). Lines = 0.5 mm. 18. *Scirtes baroalba* sp. nov. 19. *S. beccus* sp. nov. 20. *S. brisbanensis* Pic. 21. *S. calmi* sp. nov. 22. *S. crassiantennae* sp. nov. 23. *S. cygnus* sp. nov.

Ventral surface. Reddish-yellow occasionally with darker areas. Pronotal process very narrow for whole length, strongly keeled. Mesosternum short, with small elongated groove for reception of pronotal process, tip reaching level of front of mesocoxae. Rear triangular midline extension of metasternum wider than long, narrower than front extension. Metacoxal plate (Fig. 1) much wider than long, with antero-lateral corner extending some way along metasternum; hind edge very strongly concave; sides beaded; posteriolateral angles rounded. Metatrochanter small (Fig. 1). Metafemur greatly swollen, widest just before middle (Fig. 1), weakly notched on hind margin near apex. Dorsal metatibial spine relatively long. More than twice size of ventral spine and about two thirds length of segment 1 of metatarsus. Segment 1 of metatarsus a little longer than other segments combined. Ventrites with punctures small, shallow; reticulation moderate fine, more pronounced towards rear; apex of apical ventrite truncated or weakly concave.

Male

No external differences between sexes. Penis elongate, basal piece elongate, trigonium deeply bifid towards apex; single parameroid long, thin pointed (Fig. 16). Tegmen a little shorter than penis, with two well separated lobes partially enclosing penis, each lobe broadly triangular near base, thin towards apex which is weakly clubbed (Fig. 16). The distal portions of penis and tegmen often visible in preserved specimens.

Variation

Occasional specimens with lighter sutural region on elytra compared with rest of elytra.

Etymology

Named after the town where many of the specimens were collected.

Notes

A large, elongate, dark reddish species, broadly sympatric with the two other large species with concave edges to the metacoxal plates: *S. kaytae* and *S. emmae*. Separated from *S. kaytae* by the lack of dark areas on the elytra, any hint of an upturned front edge to the frons and the antenna are thinner with the segments symmetrical. Separated from *S. emmae* by the more elongate shape, darker colour and more strongly concave hind edges to the metacoxal plates. *Scirtes emmae* and *S. kaytae* are most clearly separated from this species by the male genitalia (the tips of which are often visible in preserved specimens): *S. emmae* has small triangular protrubances near the tegmen tips (Fig. 6); *S. kaytae* has a distinct hook on the tip of the penis (Fig. 12);

S. tindaleensis has swollen tips to the tegmen lobes (Fig. 16).

b) *Scirtes helmsi* species complex.

The description of *S. helmsi* is placed first, the rest are in alphabetical order.

***Scirtes helmsi* Blackburn, 1891**
(Figs 24, 40)

Type

Holotype

male; "T 3811 A7" Blackburn coll 1910-236" "*Scirtes Helmsi*, Blackb." Specimen remounted with genitalia extracted and mounted on same card. NHM.

The type locality is given as "Victoria; taken near Benalla" by Blackburn (1891).

Description (number of dissected males examined, 9)

Habitus. Length 2.8 – 4.1 mm., relatively flat, elongate.

Head. Reddish-yellow to dark chocolate-brown, often with darker patches; antenna light reddish – yellow to dark brown, basal segments lighter. Eyes small, width between eyes about 3.0x dorsal width of eye. Moderately and evenly punctate, each puncture with a moderately long seta. Frons with sides weakly diverging, front edge straight or weakly concave, edges weakly beaded. Segment 1 of antenna barrel shaped; segment 2 about half as long and narrower, barrel-shaped; segment 3 about same size as segment 2, narrower, wider towards base; segment 4 about twice length of segment 3; segments 5 – 10 subequal, narrow, cylindrical, a little shorter than segment 4; segment 11 elongate/oval, a little longer and flatter than segment 10.

Pronotum. Brown, margins narrowly lighter yellow-brown. Short, broad. Punctures moderately dense, small, each puncture with a moderately long golden seta. Hind angles obtuse, front edge sinuate, sides weakly beaded.

Scutellum. Yellow-brown, usually lighter than elytra. Equilateral triangle or slightly wider than long, lateral sides weakly convex.

Elytron. Chocolate- brown to dark brown. Sides weakly flanged in basal third. Moderately and evenly punctate, each puncture with a short yellow seta. Epipleuron relatively wide in front quarter, becoming narrower over rest of elytron, front portion flat.

Ventral surface. Yellow-brown to dark reddish-yellow, often with diffuse darker and lighter areas. Pronotal process very narrow. Mesosternum with small elongate area in midline in front for reception of pronotal process; rear tip rounded, reaching past front

of mesocoxae. Front extension of metasternum in midline small, bounded behind by ridge; rear midline extension of metasternum short, about twice as wide as long. Metacoxal plate square, with antero-lateral corner extending along metasternum; hind edge straight, sloping towards midline; sides beaded; posteriolateral angles rounded. Metatrochanter small, relatively squat, about 1.7x as long as wide. Metafemur greatly swollen, widest a little before middle, weakly notched on rear margin near apex. Dorsal metatibial spine relatively short, about twice size of ventral spine and about half length of segment 1 of metatarsus; segment 1 of metatarsus a little longer than other segments combined. Ventrites with punctures small, shallow, reticulation, moderate, fine, more pronounced towards rear; apex of apical ventrite truncated or weakly concave.

Male

Little external difference between the sexes. Basal piece of penis short, round, orientated at right angles to trigonium (viewed laterally, Fig. 40); trigonium very long and thin, 3.8x length of basal piece, tip sharply pointed; single parameroid long, a little more than half length of trigonium, with well defined apical hook (Figs 24, 40). Tegmen about half length of penis, lobes thin, elongate, well separated (Fig. 24).

Notes

A moderately sized (for the group), elongate, dark coloured species, occasionally with vague darker areas on the head, with a very long, thin, golfclub-shaped penis, the tip of which often protrudes from the abdomen in preserved specimens. Generally larger and darker than the more common *S. brisbanensis* and *S. orientalis* from which it can be reliably separated only by the male genitalia.

In spring the larvae are common in temporary streams in open forest around Forreton in the Mt Lofty Ranges of South Australia.

Specimens examined

New South Wales. 1, CSIRO Lab. Chiswick nr Armadale NSW, Jan.1966, B. Clydesdale, ANIC. **Northern Territory.** 1, Birketts Woolshed, Mus Exp 1916 Central Australia, SAMA. **South Australia.** 5, 12km N Forreton, 5/3/03, C. Watts, SAMA; 2, Watts's Gully Mt Crawford Forest, 20/11/99, C. Watts, SAMA; **Victoria.** 1, near Benalla, Helms, BMNH.

Scirtes alastairi sp. nov.

(Fig. 17)

Types

Holotype

male, "QLD Greenvale 70 Km SW. at light 17 – 28 Jan 96, A. Watts", SAMA.

Paratypes

10; 4, "QLD Greenvale 70 Km SW at light 14 – 23 Feb 96 A. J. Watts", SAMA; 1, ditto, "28 Mar – 7 Apr 1995", SAMA; 1, ditto, "6 – 15 Dec 95", SAMA; 2, ditto, "1 – 10 Mar. 95", SAMA; 2, ditto, "17 – 26 Jan 96", SAMA.

Description (number examined, 11)

As for *S. helmsi* except as follows. Length 2.2 – 2.6 mm. Uniformly light reddish-yellow, head a bit darker in some. Interorbital width 2.4x dorsal width of eye.

Male

Basal piece of penis broad, oval; trigonium about as long or a little longer, curved in lateral view; one parameroid, stout, about half length of trigonium, sinuate (Fig. 17). Tegmen about half length of penis, lobes broad basally, finger-like apically, close together (Fig. 17).

Etymology

Named after my son who collected many of the specimens described in this paper.

Notes

A small yellow species resembling *S. storeyi*, recognised by the broad basal piece, thin trigonium and stout, sinuate parameroid of penis.

Scirtes baroalba sp. nov.

(Fig. 18)

Type

Holotype

male, "12. 47S 132 .51E Baroalba Creek Springs 19 km NE by E of Mt Cahill 28.x. 72, at light, E. Britton", ANIC. Mounted on slide.

Description (number examined, 1)

As for *S. helmsi* except as follows. Length 2.8 mm. Interorbital width 2.5x dorsal width of eye. Reddish-yellow, head tending darker, basal segments of antenna lighter.

Male

Basal piece of penis very narrow; trigonium about 1.5x as long as basal piece, irregularly shaped with thin spine near apex; parameroid nearly as long as trigonium, relatively stout (Fig.18). Tegmen about as long as penis, lobes well separated, finger-like (Fig.18).

Etymology

Named after the type locality.

Notes

A small reddish-yellow species from coastal

Northern Territory with a very distinctive parameroid of the penis (Fig. 18).

Scirtes beccus sp. nov.
(Fig. 19)

Types

Holotype

male, "TE341 Tullamarine 4-9-75", ANIC.

Paratype

male, as for holotype, mounted on slide, SAMA.

Description (number examined, 2)

As for *S. helmsi* except as follows. Length 3.5 mm. Head dark reddish-yellow, pronotum reddish-yellow, darker on disc, scutellum light reddish-yellow, lighter than elytra, clytron reddish-yellow, ventral surface reddish-yellow, antenna and palps a little lighter. Interorbital width 2.7x dorsal width of eye. Metasternal plates depressed in midline, posterior-lateral angles prominently rounded, hind edges slanting inwards.

Male

Basal piece of penis elongate-oval, trigonium small, with half its length comprising a thin beak-like portion with the curve upwards (Fig. 19). Tegmen much longer than penis, lobes well separate, tips projecting well beyond penis, apical half of lobes thin, basal half, wide, triangular, partially enclosing penis (Fig. 19).

Etymology

Latin. "Beccus" – beak, a reference to the beak-like trigonium.

Notes

The relatively large size, strongly depressed metasternal plates and the beak-like trigonium to the penis distinguish this species. The metasternal plates are reminiscent of *O. improtectus* but the lower surface is still present and still provides a cover, albeit a very short one, for the metatrochanter articulation (eg Fig. 1c).

Scirtes brisbanensis Pic 1956
(Figs 20, 38)

Type

Holotype

male, with genitalia extracted and mounted on same card, "N. Guinea Biro 1900" "Queensland Brisbane" "Monotype 1956 *Scirtes brisbanensis* Pic." "*Scirtes brisbanensis* nm" "*Scirtes brisbanensis* Pic", HUNG.

Description (number of dissected males examined, 70)

As for *S. helmsi* except as follows. Length 2.2 – 3.7 mm. Interorbital width 2.5x dorsal width of eye. Reddish-yellow to dark reddish-yellow, tending to be darker towards front; ventral surface lighter.

Male

Basal piece of penis small, oval; trigonium long and thin, a little more than twice length of basal, apex expanded somewhat in dorsal/ventral plane; one or two parameroids, larger (left hand one) about two thirds as long as trigonium, abruptly narrowing into apical hook; second parameroid little more than small oval knob, often absent (Figs 20, 38). Tegmen a bit longer than penis, lobes well-separated, finger-like, tips rounded (Fig. 20).

Notes

A common, widespread species, possible more northern in distribution than *S. helmsi*. Recognised by the finger-like lobes of the tegmen and penis with a thin trigonium with slight apical dorsal/ventral expansion. The second parameroid is very small or absent, the main parameroid is abruptly hooked.

Specimens examined (dissected males only)

Queensland. 1, Big Mitchell Ck Mareeba-Molloy Road, 4 May 1967, D. H. Colless, ANIC; 1, Brisbane, 4/11/62, G. Monteith, UQIC Reg# 53678; 1, Bundaberg, 3/4/1975, at light, H. Frauca, ANIC; 1, Bushland Beach 20km N Townsville, A. J. Watts, 6-11/2/98, SAMA; 1, Caincross Nat. Pk. Via Maieny, 7/4/66, G. Monteith, UQIC Reg# 53716; 3, Cairns Gordonvale, 15/1/99, leg. A. Podlussany, HUNG; 2, Colosseum Ck, 10mls S of Miriam Vale, 20/12/66, B. Cantrell, UQIC Reg# 53663; 1, Davis Ck Rd via Mareeba, 20/1/91, S. Defaveri, QPIM; 1, Deception Bay, 29/12/62, G. Monteith, UQIC Reg# 53645; 1, Gayndah, 11/1/64, H. A. Rose, UQIC Reg# 53722; 1, Greenbank, 8/1/63, G. Monteith, UQIC Reg# 53720; 1, Greenvale 70km SW, at light, 17 – 26 Jan 96, A. J. Watts, SAMA; 2, Homestead, Silver Plains, Via Coen, 11/2/64, G. Monteith, UQIC Reg# 53651/53647; 3, Knob lagoon, 30mi. NW of Doomadgee Mission, NW Qld., 22/5/72, G. Monteith, UQIC Reg# 53705; 1, Lawes, 6/4/63, A. MacQueen, UQIC Reg# 53699; 1, Ditto except, 18/12/62, G. Monteith, UQIC Reg# 53700; 2, 23km N of Mareeba, 12/11/89, R. I. Storey, at light, QPIM; Nardello's Lagoon nr Mareeba, 29/3/96, C. Watts, SAMA; Tin Can Bay. 22/1/99, leg. A. Podlussany, HUNG; 1, 30km N Marlborough, 24/2/81, Hangay & Herozeg, No 244, HUNG; 1, 21km E Mareeba, 21/1/91, at light, R. I. Storey, QPIM; 1, Moorehead R. N of Laura, 20/1/90, Fay & Halfpapp, QPIM; 1, Paradise Falls Bunya Mts Nat. Pk. 26.52S 151.35E, 6/10/84,

I. Naumann J. Cardale, ANIC; 1, 7km NE Tolga, Feb 1988, at light, Storey R. & D. E. Faveri, QPIM; 1, Tolga, 13 – 20/11/85, at light, J. D. Brown, QPIM; 1, Whiteside Xing, N. Pine River, 12/7/63, G. Monteith, UQIC Reg# 53718. **Northern Territory.** 1, 4ml SW Alice Springs, 18/2/66, Britton, Upton & McInnes, ANIC; 4, Batten Creek 16.10S 136.31km WSW Borrooloola, 15/4/76, at light, J. E. Feehan, ANIC; 3, 22km WSW of Borrooloola 16.08S 136.06E, 16/4/76, at light, J. E. Feehan, ANIC; 3, Bessie Springs, 16.40S 135.51E 8km ESE of Cape Crawford, 12/4/76, at light, J. E. Feehan, ANIC; 1, 1km N of Boko Hill SW of Borrooloola 12.26S 136.01E, 14/4/76, Key, Balderson *et al.*, ANIC; 2, Calliope R 14ml SE Gladstone 23.50S 151.13E, 23/1/70, at light, S. Misko, ANIC; 46km SSW of Borrooloola 16.28S 136.09E, 23/4/76, at light, J. E. Feehan, ANIC; 1, Katherine Gorge, 26/10/75, at light, M. J. Muller, ANIC; 2, McArthur River 16.10S 136.05E 48km SW by S of Borrooloola, at light, 13/4/76, J. E. Feehan, ANIC; 2, McArthur River 16.47S 135.45E 14km SW of Cape Crawford, 11/4/76, J. E. Feehan, ANIC; 1, Surprise Creek 16.25S 136.05E 45km SW by S of Borrooloola, 14/4/76, at light J. E. Feehan, ANIC; 2, Roe Creek 12km SW by W of Alice Springs 23.46S 133.46E, 27/9/87, M. S. Upton, ANIC; 1, Tindale 14.31S 132.22E, 1 – 20/12/67, at light, W. J. M. Vestjens, ANIC. **New South Wales.** 4, Bogan River, SAMA; 2, New England, Glenrock, 5/11/97, leg. G. Hangay, HUNG; 1, Lachlan River 15km SW of Eublong, 28/12/75, Z. Licpa, ANIC; 2, Tamworth, Lea, SAMA; 2, Yuragir NP Station Creek, 20/11/82, J & E Doyen, at light, ANIC. **South Australia.** 1, 21km SE of Oodnadatta 30.40S 135.37E, 20/9/78, M. S. Upton, ANIC. **Victoria.** 1, Benalla, 18/2/67, G. Monteith, UQIC Reg# 53682. **Western Australia.** 5, 6km S Pinjarra, 23/10/96, C. Watts, SAMA

Scirtes calmi sp. nov.
(Fig. 21)

Types

Holotype

male; ~15.36S 125.15E CALM Site 28/3 4km W of King Cascade W.A. 12 – 16 June 1988, T. A. Weir", "at light open forest", ANIC.

Paratypes

3; 2, as for Holotype, 1 ANIC, 1 SAMA; 1, "6.31S 125.16E CALM Site 25/1 Synnot Ck. W.A. 17 – 20 June 1988 T.A.Weir", "at light open forest", ANIC.

Description (number examined, 4)

As for *S. helmsi* except as follows. Length 2.7 mm. Light reddish-yellow, diffusely darker towards front; ventral surface and appendages lighter. Interorbital

width 2.5 x dorsal width of eye. Punctures on dorsal surface relatively large.

Male

Basal piece of penis broad, oval; trigonium about as long as basal piece, triangular, apex rounded; two parameroids each relatively stout, curved, about as long as trigonium, left hand one slightly hooked, right hand one with tip missing in only specimen (reconstructed in illustration) (Fig. 21). Tegmen about half-length of penis, lobes narrow, slightly notched on outside near apex (Fig. 21).

Etymology

Named after CALM (Western Australian Department of Conservation and Land Management) who financially supported the collection of the species.

Notes

Most easily recognised by the broad aedeagus with two strong parameroids.

Scirtes crassiantennae sp. nov.
(Fig. 22)

Types

Holotype

male, "AUSTRALIA, n. Qld. 11km WSW of Petford, 23.1.1988, R.I.Storey, at light", QPIM.

Paratype

1, male, "AUSTRALIA, n. Qld Petford-Irvinebank Rd, 6.iv.1992, Cunningham, DeFaveri", QPIM.

Description (number examined, 2)

As for *S. helmsi* except as follows. Length 2.5 mm. Uniformly reddish-yellow. Interorbital width 2.5x dorsal width of eye. Segments of antenna relatively short, stout, segment 10 only a little longer than wide.

Male

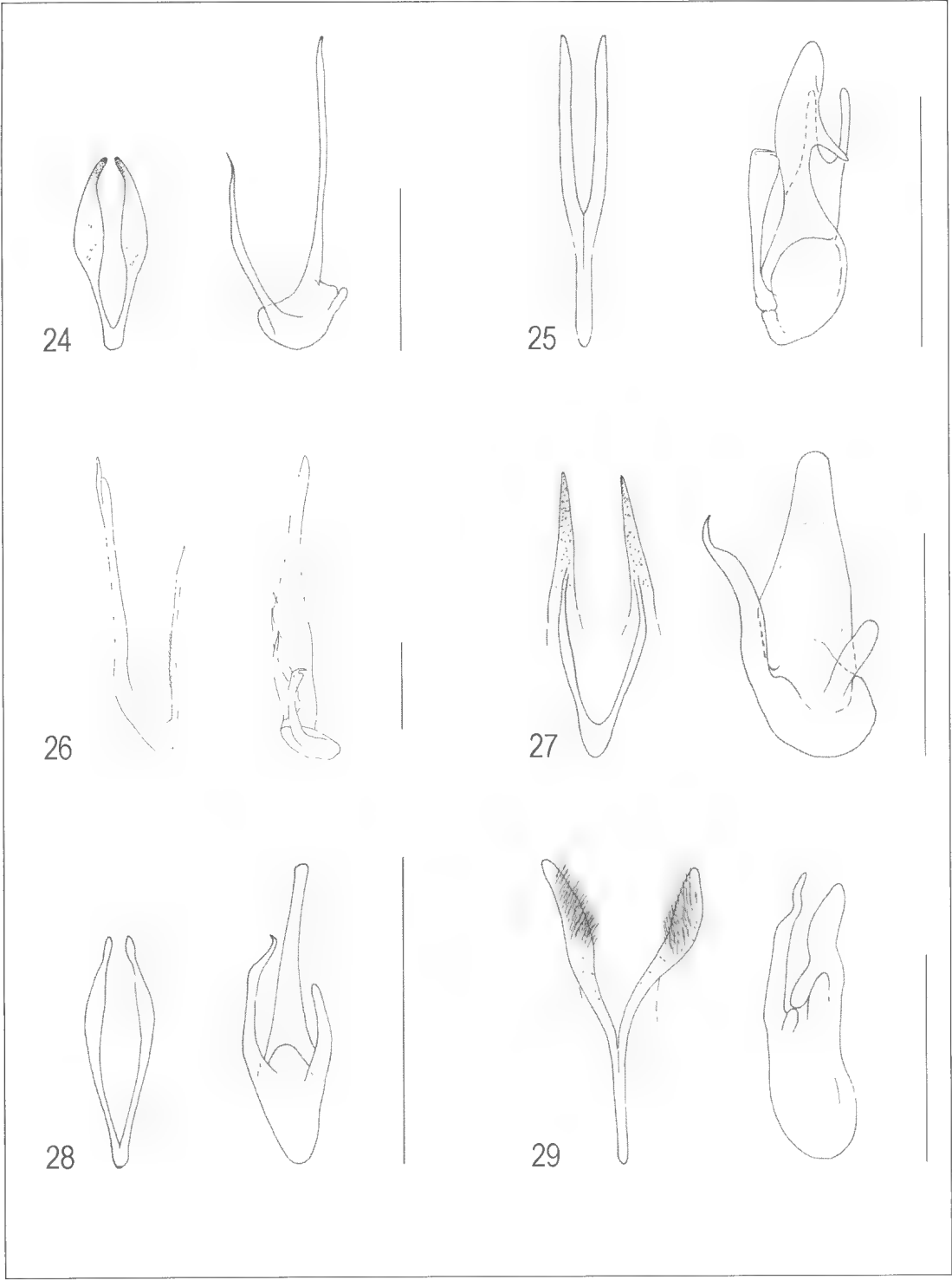
Basal piece of penis broad, oval; trigonium narrowly triangular, about twice as long as basal piece, sharply pointed; single parameroid about as long as basal piece, moderately broad, with small but distinct hook at apex (Fig. 22). Tegmen longer than penis, lobes well separated, relatively narrow, broader in middle, inner edge serrated in apical half (Fig. 22).

Etymology

Latin. "Crassus" – thick. A reference to the thick antennae.

Notes

A small, uniformly yellow, species (one specimen



Figs 24-29. Dorsal views of tegmen (left) and penis (right). Lines = 0.5mm. 24. *Scirtes helmsi* Blackburn. 25. *S. musica* sp. nov. 26. *S. nalyerensis* sp. nov. 27. *S. nigerpalpus* sp. nov. 28. *S. orientalis* sp. nov. 29. *S. peniculus* sp. nov.

has diffuse dark areas on head and pronotum) known only from the two type specimens. Recognised by the tegmen lobes serrated on their inner edges. The antennae (male) are noticeably stouter than in most other species in the *S. helmsi* group.

Scirtes cygnus sp. nov.
(Fig. 23)

Types

Holotype

male, "Cow Bay, N. of Daintree, N. Qld. 7-20.ii.1984, I. C. Cunningham", QPIM.

Paratypes

7; 3, as for holotype, 1, QPIM, 2 (1 slide), SAMA; 1, "Cow Bay, N of Daintree R., N. Qld, 18-25.i.1984, Storey & Cunningham", QPIM; 1, Cow Bay, N of Daintree, N. Qld, 25.i-7. ii. 1984, I. C. Cunningham", QPIM; 1, "Iron Range, Cape York Pen. N. Qld. 1-4. v. 1973, G. B. Monteith", QM.; 1, ditto except '26 May - 2 June 1971', "UQIC Reg# 53662", UQIC.

Description (number examined, 8)

As for *S. helmsi* except as follows. Length 2.0 - 2.8 mm. Uniformly light reddish-yellow. Interorbital width 2.2x dorsal width of eye.

Male

Basal piece of penis relatively large, narrowly oval; trigonium narrow, about two thirds as long as basal, slightly expanded at apex; single parameroid as long as trigonium, broad, with hook at apex (Fig. 23). Tegmen longer than penis, lobes well-separated, relatively thin, with large triangular expansion in middle partially enclosing penis (Fig. 23).

Etymology

Latin. "Cygnus" - swan, a reference to the swan-like parameroid.

Notes

A small golden species recognised by the swan-shaped parameroid and triangularly shaped middle sections of the tegmen lobes which partial enclose the penis.

Scirtes musica sp. nov.
(Fig. 25)

Types

Holotype

male, "15.03S 145.09E 3 km NE of Mt Web Qld., 1-3 Oct. 1980, T. A. Weir", ANIC.

Paratype

male, as for Holotype, slide, SAMA.

Description (number examined, 2)

As for *S. helmsi* except as follows. Length 1.8 - 2.4 mm. Uniformly light reddish-yellow. Interorbital width 2.4x dorsal width of eye.

Male

Basal piece of penis short, round; trigonium relatively broad, twice as long as basal, asymmetric with a strong lateral spine; two parameroids, both nearly as long as trigonium, left hand one thin, widening towards apex, terminating in a small hook, right hand one bifid with two long finger-like pieces (Fig. 25). Tegmen about as long as penis, in shape of tuning-fork (Fig. 25).

Etymology

Latin. "Musica" - music, a reference to the tuning-fork shape of the tegmen.

Notes

A small very golden species recognised by the complex penis with a prominent spine and the tuning-fork shaped tegmen.

Scirtes nalyerinensis sp. nov.
(Fig. 26)

Types

Holotype

male, "WA Lake Nalyerin 33 08S 116 22E CHS Watts 6/10/03", SAMA.

Paratypes

5 (3 slides), as for holotype, SAMA.

Description (number examined, 6)

As for *S. helmsi* except as follows. Length 3.5 - 4.2 mm, elongate oval. Light chestnut, head, disk of pronotum, antennae other than basal segments darker. Side of elytron weakly flanged in front half. Interorbital width 3.0x dorsal width of eye.

Male

Basal piece of penis very small, oval; trigonium long, relatively broad in basal half narrower in apical half, basal half with additional 'flap' adpressed to one side; single parameroid relatively short, thin, with abrupt apical hook (Fig. 26). Tegmen lobes thin, asymmetric, one longer than penis with tip sharply pointed and projecting well beyond tip of penis; shorter lobe thin and about two-thirds length of other, with small setae in basal half (Fig. 26).

Etymology

Named after the type locality.

Notes

A moderately sized species with relatively large

eyes and an extremely long narrow lobe to the tegmen which projects well beyond the end of the penis which itself is relatively long. At first sight very reminiscent of *S. helmsi* but in that species it is the trigonium which is elongate and projecting.

Known only from Lake Nalyerin in the Jarrah forest of Southwestern Western Australia. The holotype was collected from a flowering *Hakea* beside the lake. The other specimens were bred from larvae that were abundant in the shallow lake.

***Scirtes nigerpalpus* sp. nov.**
(Figs 27, 42)

Types

Holotype

male, "WA 2.5 Km W Serpentine 23/9/00 C. Watts", SAMA.

Paratypes

73, as for holotype, SAMA; 65, "12k W Serpentine WA, 24/10/96, C. Watts", SAMA; 9, "6 km S Pinjarra, 23/10/96, C. Watts", SAMA; 1, "Swan R Lea", SAMA; 3, "32.23S 115.59E 3km SE by S Serpentine WA 2 Oct 1981 I. D. Naumann J. C. Cardale", ANIC; 1, "33.51S 123.00E Thomas River 23 km NW by W of Mt Arid WA 4-7.xi.1977 J. F. Lawrence", ANIC.

Description (number examined, 74)

As for *S. helmsi* except as follows. Length 2.6–3.7 mm. Head black or very dark brown; pronotum dark brown to black with narrow yellowish border; scutellum and elytra dark brown to black; ventral surface dark brown to black, trochanters and knees lighter. Interorbital width 3.0x dorsal width of eye. Metafemur relatively narrow (Fig. 1b).

Male

Basal piece of penis relatively short, oval; trigonium relatively broad, narrowing towards apex, about 2x length of basal piece; two parameroids, left hand one relatively broad, nearly as long as trigonium, narrowing abruptly near apex into thin, slightly curved, apical portion, right hand one short, thumb-like (Fig. 27). Tegmen about as long as penis, lobes well separated, narrow, anther-like, tips pointed (Fig. 27).

Etymology

Latin. "Niger" – black.

Notes

A moderately large almost black species recognised by its dark colour, including the base of the antennae and the palpi, moderately expanded metafemurs, relatively small eyes, short basal piece

to the penis, broad spatulate trigonium and two parameroids, the larger, left hand one, with a relatively abrupt apical hook.

Like *S. pinjarraensis*, *S. nigerpalpus* is only known from near Pinjarra in Western Australia. It can be separated from *S. pinjarraensis*, which is common in the same habitat, by its larger size, smaller eyes and darker colour, including antennal bases, palpi and scutellum. In a few specimens the pronotum is reddish-yellow in contrast to the dark head. In these the antenna and palpi are lighter than usual. *Scirtes orientalis* from Eastern Australia seems close but is much lighter coloured, has broader metafemurs, larger eyes and has a narrower trigonium to the penis.

The larvae are common in shallow ditches in spring and the adults are common on nearby flowering shrubs.

***Scirtes orientalis* sp. nov.**
(Figs 28, 43)

Types

Holotype

male, "Russell R. at Belenden Ker Landing, N Q., 5m 24 Oct-9 Nov. 1981 EARTHWATCH/QLD.MUSEUM Malaise trap, rainforest", ANIC.

Paratypes

24; 2, as for holotype, one of which bears additional label "A.N.I.C. COLEOPTERA Voucher No 83-0387"; 2, "35.16S 149.06E Black Mtn ACT, 600m., Dec 1987, M.E.Irwin, ex Malaise trap", ANIC; 1, "Brandy Creek Qld. 18 km E Proserpine, 100m., 21 June – 10 Aug. 1982, S & E Peck SBP43", ANIC; 1, "Bruxner Park, Via Coff's Harbour, 25.xi. 1967. NSW. G. Monteith" "UQIC Reg# 53712", UQIC; 1, "Cann River, N. Vic, 28.i.1967 G. Monteith" "UQIC Reg# 53715", UQIC; 1, "AUSTRALIA: n Qld. Danbulla S.F. 11km NE of Yungaburra, 21.12.1986, Storey & De Faveri", QPIM; 1, "AUSTRALIA: N. QLD. Danbulla S.F. via Yungaburra, 13.11.1992, at light, Storey, De Faveri & Huwer", QPIM; 1, "Kiola Forest Pk. NSW, 20m., 15km N Batemans Bay, 30 Aug. 1982, S. & J. Peck SBP119" "wet sclerophyll litter", ANIC; 1, AUSTRALIA. n Qld. 5 km NNW of Kuranda 1.v-14.vi.1985 Storey & Halfpapp" "MDFI Intercept Trap Site No 24", QPIM; 2, "AUSTRALIA Narrabeen" "NSW", "22.2.1984, leg. G. Hangay", HUNG; 1, ditto except 29.12.1984, SAMA; 1, ditto except 25.12.1984, HUNG; 1 slide, ditto "23-xii-1983" SAMA; 2, Russell R. at Bellenden Ker Landing, N.Q. 5m., 24 Oct-8 Nov 1981, EARTH WATCH/QLD.MUSEUM, Beating, rainforest", QM; 6, "Russell R. at Belenden Ker Landing, N Q., 5m Nov 1 1981 EARTHWATCH/QLD.MUSEUM"

"Q.M. BERLESATE NO 361, 17.16.S, 145.57E, Palm swamp. Moss on tree trunks", 5 QM, 1 slide SAMA.

Description (number of dissected males examined, 23)

As for *S. helmsi* except as follows. Length 2.4 - 3.2 mm. Dorsal surface reddish-yellow with darker markings on head and pronotum; ventral surface reddish-yellow, palpi and antennal bases lighter. Interorbital width 2.2x dorsal width of eye.

Male

Basal piece of penis small, oval; trigonium elongate triangular, a little more than twice length of basal piece; two parameroids, left hand one largest, about two-thirds as long as trigonium, relatively broad, with terminal hook, right hand one finger-like, about half length of other (Fig. 28). Tegmen about two-thirds the length of the penis, lobes moderately separated, thumb-like (Fig. 28).

Etymology

Latin. "Orient" - east, a reference to its distribution in Australia.

Notes

The extent of the dark markings on the head and pronotum are variable and in some specimens the base of the elytra is diffusely darker than the rest of the elytra. The male genitalia resemble *S. nigerpalpus* but have the trigonium consistently narrower and the tips of the tegmen lobes rounded rather than pointed. They also differ from *S. nigerpalpus* in their much lighter colour, broader metafemurs and larger eyes.

Four specimens from the Northern Territory may belong to this species. The male genitalia (one specimen only) appear close but they are smaller (2.1 - 2.4 mm long) and the metafemurs are a little narrower: 2.1x as long as wide as against 1.8x.

Associated specimens

2, 12.47S 132. 51E Baroalba Creek, nr. source. rainforest, 19km NE by E of Mt Cahill, NT., 29/10/72 by sweeping, D. Colless", ANIC; 2, 12.47S 132. 51E Baroalba Creek, 19km NE by E of Mt Cahill, NT., 29/10/72, at light, E. Britton, ANIC.

Scirtes peniculus sp. nov.

(Fig. 29)

Types

Holotype

male; 12.57S 132.33E Jim Jim Creek, N.T. 19 km WSW of Mt Cahill, 24.10.72, at light, E. Britton", ANIC.

Paratypes

8; 5, as for holotype, 2 ANIC, 3 SAMA; 1 slide, "12. 47S 132.51E Baroalba Creek Springs, NT 19 km NE by E of Mt Cahill 28.x.72, at light, E. Britton", SAMA; 1, "14.49S 126.49E Carson escarpment W.A., 9 - 15 Aug. 1975, I.F.B. Common and M. S. Upton", ANIC; 1, "15.02S 126.55E Drysdale River WA., 3 - 8 Aug 1975, I.F.B. Common and M. S. Upton", ANIC; 2, "12.52S 132.47E Nourlangie Creek, N.T. 8km E of Mt. Cahill, 27.x.72, at light, E. B. Britton", ANIC; 1, "Jabiru, N.T. 17-20. 9.1982, R.I.Storey, at light", QPIM; 1 slide, "12.46S 132 39E 12 km NNW of Mt Cahill, NT. 25.x.72, at light, E. Britton", SAMA; 1 slide, "12. 50S, 132. 51E 15 km E by N of Mt Cahill, NT. 29.x.72, at light, E. Britton", SAMA; 1, "12.50S 132,51E 16km E by N of Mt. Cahill.N.T. 16 xi.1972 T. Weir & A. Allwood", NTM; 1, "12.52S 132.46E Nourlangie Creek 6km E of Mt Cahill, N.T. 12.x.1972 T. Weir", NTM.

Description (number of dissected males examined, 6)

As for *S. helmsi* except as follows. Length 1.8 - 2.5 mm. Light reddish-yellow to quite dark chestnut, head tending darker, antennae, palpi and extremities of legs lighter. Interorbital width 2.0x dorsal width of eye.

Male

Basal piece of penis rather narrowly oval; trigonium shorter, about half as long and wide, irregularly shaped, quite strongly curved in lateral view; single parameroid about as long as basal piece, relatively stout, sinuate or weakly hooked (Fig. 29). Tegmen a little longer than penis, lobes with very prominent oval area of strong setae a little below apex (Fig. 29).

Etymology

Latin. "Peniculus" - brush/tuft, a reference to the brush-like groups of setae on the tegmen.

Notes

A small, relatively dark, northern species, recognised by the irregularly shaped trigonium and tegmen lobes with a strong bush of setae near apex.

Scirtes pinjarraensis sp. nov.

(Figs 30, 39)

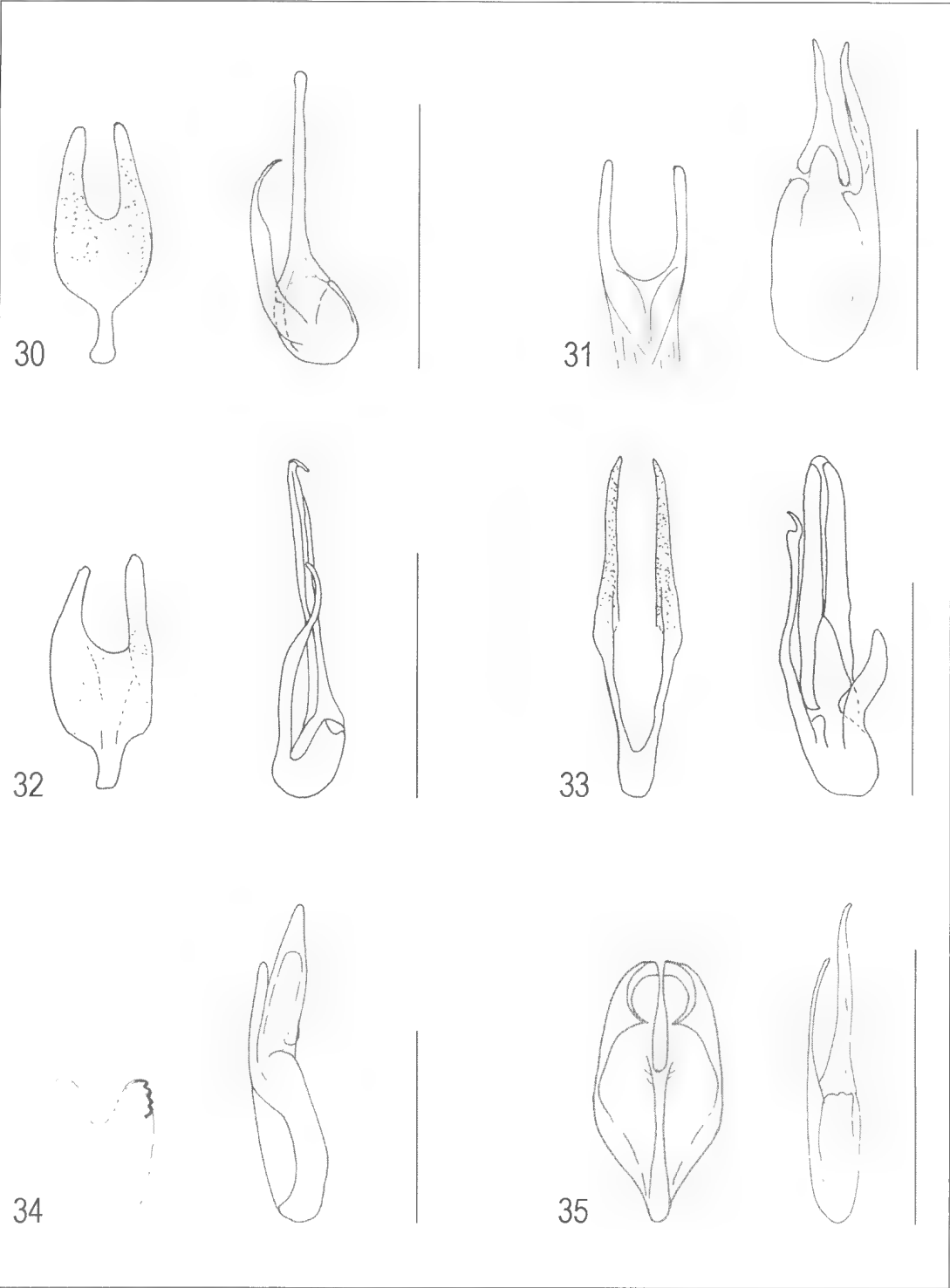
Types

Holotype

male, "12 K W Serpentine WA, 24/10/96, C. Watts", SAMA.

Paratypes

45; 40 (4 slides), "12 K W Serpentine WA,



Figs 30- 35. Dorsal views of tegmen (left) and penis (right). Lines = 0.5mm. 30. *Scirtes pinjarraensis* sp. nov. 31. *S. podlussanyi* sp. nov. 32. *S. pygmaeus* sp. nov. 33. *S. rivularis* sp. nov. 34. *S. spatula* sp. nov. 35. *S. storeyi* sp. nov.

24/10/96, C. Watts", SAMA; 5, "6K S Pinjarra WA, 23/10/96, C. Watts", SAMA.

Description (number examined, 46)

As for *S. helmsi* except as follows. Length 1.7–2.7 mm. Head dark reddish-yellow; pronotum dark reddish-yellow with yellowish borders of variable width; scutellum yellow; elytron reddish-yellow to dark reddish-yellow; ventral surface reddish-yellow with diffuse lighter areas; base of antenna lighter. Interorbital width 2.5x dorsal width of eye.

Male

Basal piece of penis short, oval; trigonium long and thin, 2.5–3.0 x as long as basal piece, slightly knobbed at tip; single parameroid nearly as long as trigonium, relatively narrow, rapidly narrowing in apical quarter to a thin curved portion (Fig. 30). Tegmen a bit shorter than penis, lobes well separated, narrow, tips pointed (Fig. 30).

Variation

There is considerable variation in the colour of the head and pronotum from completely reddish-yellow to having extensive areas of lighter colour.

Etymology

Named after the type locality.

Notes

A small species with a very limited known distribution, recognised by the short basal piece to the penis and the single parameroid with long, thin, curved apical portion (Fig. 30).

In spring adults are common on flowering shrubs beside water in the area around Pinjarra in the Southwest of Western Australia. Here the larvae are common among dead leaves and debris in shallow ditches. *Scirtes nigerpalpus* is also abundant in the same places. Apart from differences in the penis *S. nigerpalpus* is larger and almost totally black including antennal bases and palpi.

Scirtes podlussanyi sp. nov.
(Fig. 31)

Type

Holotype

male, AUSTRALIA Queensland Tin Can Bay, 99.1.22.leg. A. Podlussany" SAMA.

Description (number examined, 1)

As for *S. helmsi* except as follows. Length 2.7 mm. Light chestnut, scutellum, rear margin of pronotum, appendages and ventral surface reddish-yellow. Interorbital width 2.6x dorsal width of eye.

Male

Basal piece of penis large, oval; trigonium a little shorter, broad at base, evenly narrowing to rounded apex, curved upwards towards tip; single parameroid arising low on basal piece, relatively narrow, tip nearly reaching apex of trigonium (Fig. 31), viewed laterally basal half thick, apical half thinner and curved. Tegmen a bit shorter than penis, lobes well separated, narrowly finger-like (Fig. 31).

Etymology

Named after the collector.

Notes

A small dark species recognised by the large basal piece to the penis, parameroid nearly as long as trigonium and stirrup-like tegmen.

Scirtes pygmaeus sp. nov.
(Fig. 32)

Types

Holotype

male, "WA 1 km W Kodjup Swamp 34 24 03S 116 38 37E CHS Watts 1/10/03", SAMA.

Paratypes

8 (3 slides), as for holotype, SAMA.

Description (number examined, 9)

As for *S. helmsi* except as follows. Length 2.2–2.5 mm, oval. Reddish-brown, scutellum, narrow border of pronotum, basal segments of antennae, palpi, portions of head and ventral surface including legs yellowish. Side of elytron weakly flanged in front half. Interorbital width 3.2x dorsal width of eye.

Male

Basal piece of penis small, oval, trigonium long and narrow, 2.5x the length of the basal piece, tip sharply bent to one side; single parameroid arising low on the basal piece, long, thin, curved towards apex (Fig. 32). Tegmen a little shorter than penis, broad lobes relatively short, well separated, slightly asymmetric (Fig. 32).

Etymology

Latin. "Pygmaeus" = dwarf, a reference to its small size.

Notes

A small, dark, Western Australian species with pale bases to the antennae. The long trigonium is unique within Australian *Scirtes* in having the tip sharply bent to one side.

All specimens were reared from larvae that were abundant in dead grass and other vegetation at the

edges of a large, seasonal, *Melaleuca* swamp.

***Scirtes rivularis* sp. nov.**
(Figs 33, 41)

Types

Holotype

male, "WA 2km SW North Dandalup, 2/10/2003, C. H. S. Watts".

Paratypes

3 (1 slide), as for holotype, SAMA.

Description (number examined, 4)

As for *S. helmsi* except as follows. Length 3.4–3.5 mm, elongate oval. Light to relatively dark chestnut, head, areas on disk of pronotum, middle and apical segments of antennae and much of ventral side darker. Side of elytron weakly flanged in front half. Interorbital width 4.5x dorsal width of eye.

Male

Basal piece of penis oval, trigonium relatively long and broad, about twice as long as basal piece, apex rounded; two parameroids, left hand one long, nearly as long as trigonium, narrow, abruptly hooked at apex, right hand one about half length of left hand one, finger-like. (Figs 33, 41). Tegmen a little longer than penis, lobes well separated, finger-like, narrowing towards tips, tips rounded (Fig. 33).

Etymology

Latin. "Rivularis" – of a brook, a reference to the larval habitat.

Notes

A moderate sized species with relatively small eyes dark head, variegated pronotum and light coloured bases of legs. Close to the Eastern Australian *S. orientalis* but a little larger, darker and the parameroid crenulate on the bottom edge and the hook more abrupt (Fig. 41). The area of small spines on the top of the trigonium is only clearly visible on prepared slides.

All the known specimens were bred from larvae collected from the headwaters of a small stream running off an escarpment in the Darling Ranges in forest country east of North Dandalup in South-west Western Australia.

***Scirtes spatula* sp. nov.**
(Fig. 34)

Types

Holotype

male, "Qld Greenvale 70km SW, at light, 29 Jan – 4 Feb 1997, A. J. Watts", SAMA.

Paratypes

2 males; 1, "Tolga N. Qld. i-ii.1980, N.Gough, J. D. Brown", QPIM; 1, "Katherine, N.T. 23.i. 1971 T. Weir & A. Allwood", NTM.

Description (number examined, 3)

As for *S. helmsi* except as follows. Length 3.3–3.4 mm. Dull reddish-yellow, parts of head and pronotum slightly darker. Elytra moderately flanged in front half. Width between eyes about 3x dorsal width of eye.

Male

Basal piece of penis narrowly oval; trigonium a little longer, moderately broad, sides parallel until close to apex where they converge to rounded tip; single parameroid arising low on basal piece, about as long as trigonium, relatively narrow, narrowing slowly towards rounded tip (Fig. 34). Tegmen only about half length of penis, lobes broad, moderately enclosing penis, with raised, strongly chitinated, toothed, inner portion near middle (Fig. 34).

Etymology

Latin. "Spatula" – broad flat tool, a reference to the shape of the trigonium.

Notes

A moderately large species, recognised by the elytral edge moderately flanged, the spatulate trigonium, the single parameroid without a terminal hook and the enclosing, toothed tegmen.

***Scirtes storeyi* sp. nov.**
(Fig. 35)

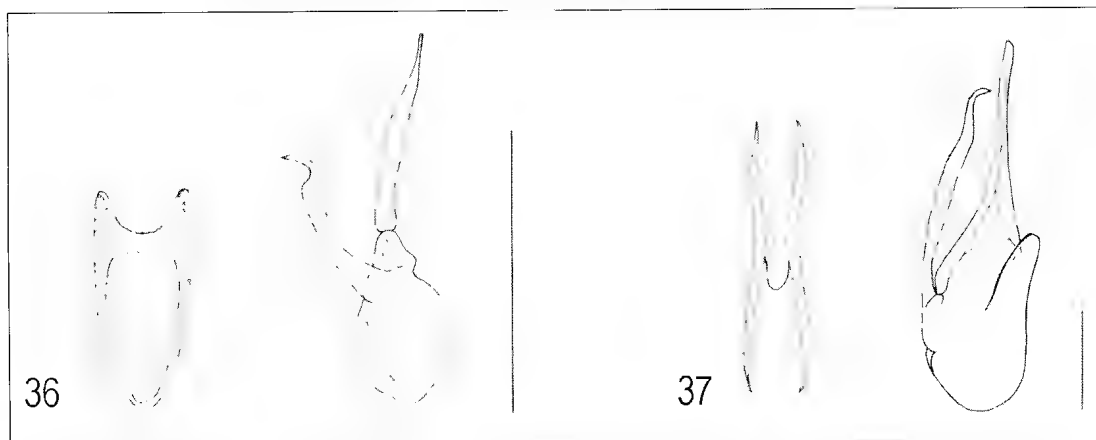
Types

Holotype

male "QLD Greenvale 70km SW at light, 12 – 21 Apr 1995 A. J. Watts", SAMA.

Paratypes

17; 1, as for holotype, SAMA; 1, "Biloela QLD 3 Apr, 1982 R. Howell", ANIC; 1, AUSTRALIA n. Qld Granite Gorge 9.5 km SW of Mareeba, 9.12.1987, at light, Storey & de Faveri", QPIM; 2, "Qld Greenvale, 70 km SW, at light, 14 – 23 Feb 96, A. J. Watts, SAMA; 1 slide, ditto, "Feb 96", SAMA; 1 slide, ditto, "6 – 15 Dec 95", SAMA; 1, "Iron Range Cape York Pen, N. Qld. 1-4.v.1973 G B Monteith", QM; 1, "Homestead, Silver Plains Via Coen, N. Qld 20.x11.1964. G. Monteith", "UQIC Reg # 53650", UQIC; 1, "Australia, NT Humpty Doo 6km E, 9.2-4.3.1987, R. I. Story", QPIM; 1, "Kalpower X-ing 75 km NW of Laura N. Qld. 2.iv.1983, at light R. I. Storey", QPIM; 1, "4 miles S.W. of Lee Point Darwin NT, 6 Mar 1967, M. S.



Figs 36-37. Dorsal views of tegmen (left) and penis (right). Lines = 0.5mm. 36, *Scirtes triangulus* sp. nov. 37, *S. victoriaensis* sp. nov.

Upton", ANIC: 1 slide, "15.38S 125.125E CALM Site 28/3 4km W of King Cascade WA, 12-16 June 1988 T. A. Weir", "at light open forest", ANIC: 1, "15.10S 145.07E 3.5km SW by S Mt. Baird QLD 3-5 May 1981 A. Calder", ANIC: 2, "AUSTRALIA n. Qld 11km WSW of Petford, 23.1.1988, R. I. Storey, at light", QPIM: 1, "Russell R at Bellenden Ker Landing N.Q. 5m 24 Oct - 9 Nov 1981 EARTHWATCH QLD MUSEUM", "A.N.I.C. COLEOPTERA Voucher 83-0587", QM: 1, "16.31S 126.16E CALM Site 25/1 Synot Ck WA, 17-20 June 1988, T. A. Weir", ANIC: 1, "Murgene la, NT 4.viii.1982 C. Wilson & S. Collins", NTM: 1", N.T., Darwin, Lee Pt on Eucalyptus blossom 28.i.1980 M.Malipatil", NTM.

Description (number examined, 17)

As for *S. helmsi* except as follows. Length 2.0-2.4 mm. Light reddish-yellow, a bit darker on head. Interorbital distance 2.0x dorsal width of eye.

Male

Basal piece of penis narrowly oval, trigonium somewhat longer, thin, slightly sinuate in dorsal view; weakly curved in lateral view; single parameroid, thin, nearly as long as trigonium (Fig. 35). Tegmen as long as penis, lobes wide, partially enclosing aedeagus, with well-marked transverse, strongly chitinized ridge on inside near apex (Fig. 35).

Etymology

Named after Ross Storey, the Curator of Entomology at QPIM who kindly provided many of the specimens used in this revision including this species.

Notes

A small, light coloured, northern species, recognised by the long, thin, single parameroid and the enclosing tegmen with chitinized ridge.

Scirtes triangularis sp. nov. (Fig. 36)

Types

Holotype

male, "Kuranda Range State Forest N. Qld 20 Apr. 1967 D. H. Colless", ANIC.

Paratypes

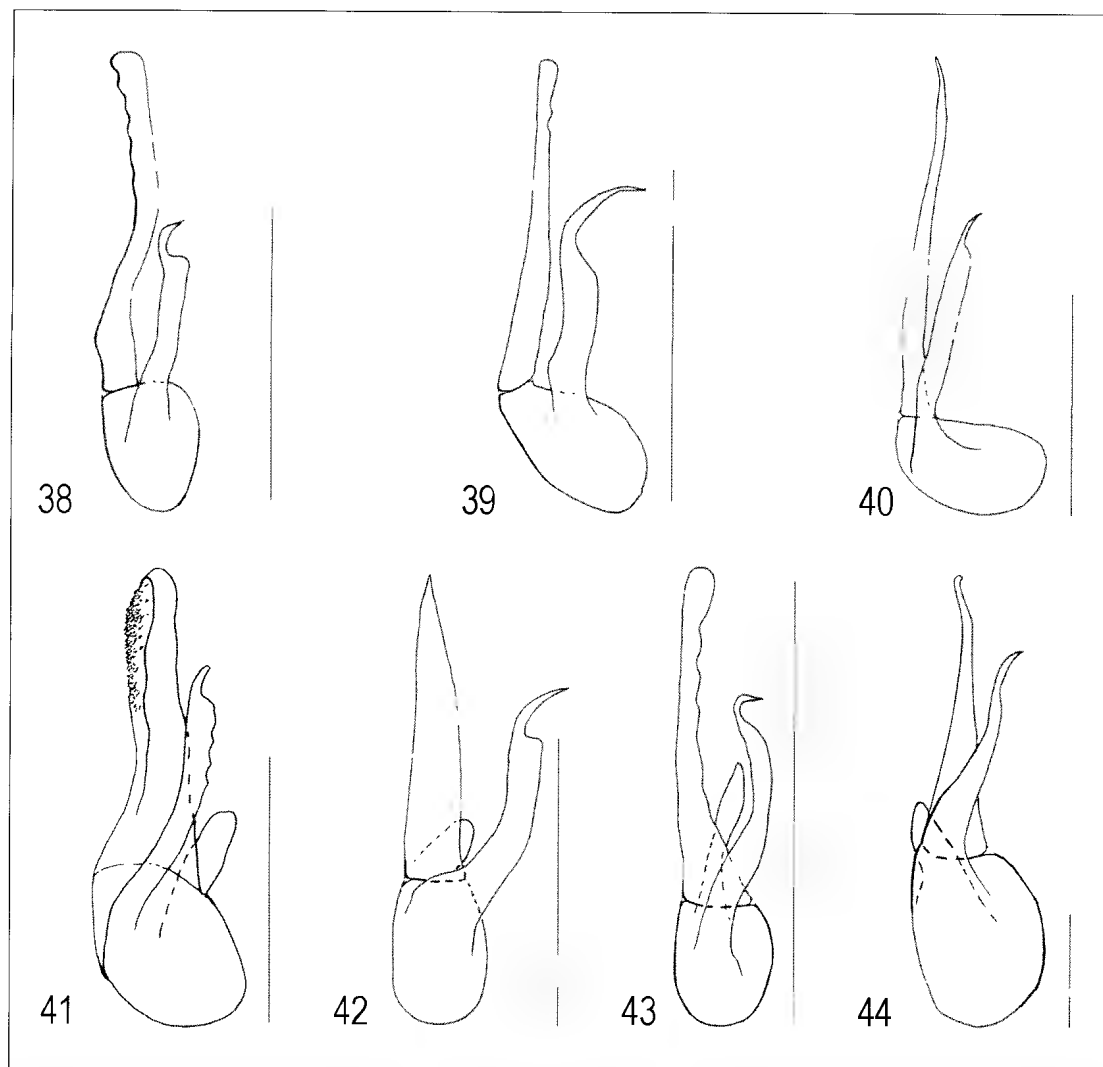
2: 1, as for holotype, ANIC; 1 slide, "Bamboo Ck., near Miallo N of Mossman, N. Qld. 25 Apr. 1967 D. H. Colless", SAMA.

Description (number examined, 3)

As for *S. helmsi* except as follows. Length 3.1 mm. Head, pronotum, scutellum and ventral surface reddish-yellow, elytra dark chestnut, lighter on disc with small triangular area of yellow near suture at apex. Interorbital width 2.5x dorsal width of eye.

Male

Basal piece of penis oval; trigonium almost as long, relatively narrow, with thin point at apex, sharply deflexed near base so that most of trigonium at right angles to rest of penis; single parameroid relatively narrow, as long as basal piece, weakly hooked at apex (Fig. 36). Tegmen about half length of penis, undivided except for apical fifth, lobes short, thumb-like (Fig. 36).



Figs 38-44. Lateral views of the penises of *Scirtes helmsi*-like species. Lines = 0.5mm. 38. *S. brisbanensis* Pic. 39. *S. pinjarraensis* sp. nov. 40. *S. helmsi* Blackburn. 41. *S. rivularis* sp. nov. 42. *S. nigerpalpus* sp. nov. 43. *S. orientalis* sp. nov. 44. *S. victoriaensis* sp. nov.

Etymology

Latin "Triangulus" having three angles, a reference to the triangular marking on the elytra.

Notes

A little known species with darkish elytra with distinctive triangular yellow area at apex in middle. Recognised by the sharply bent trigonium of the penis and short tegmen lobes.

Scirtes victoriaensis sp. nov.
(Figs 37, 44)

Types

Holotype

male, "Dimboola, Vic. Caravan Park, light trap 18.xi.73, S Misko", ANIC.

Paratypes

4: 1, "Benalla, Vic. 18.ii. 1967 G. Monteith" "UQIC Reg # 53681." UQIC; 1, "Kiata, V. 20.ix.18 F. E. Wilson", NMV; 1, "Noble Park, V. F. E. Wilson 28.6.19", "Scirtes helmsi id by J. Armstrong", NMV; 1, "Pakenham 31.12. 22 Vic C. Oke". "Scirtes helmsi id by J. Armstrong", NMV.

Description (number examined, 5)

As for *S. helmsi* except as follows. Length 3.8–4.3 mm, elongate oval. Chestnut, base of antenna lighter, parts of ventral surface darker; covered with prominent silver setae. Side of elytron weakly flanged in front half. Interorbital width 2.7x dorsal width of eye.

Male

Basal piece of penis oval, trigonium longer, widely triangular at base, rapidly narrowing to narrow shaft which is slightly expanded dorsal/ventrally, sharp ventral ridge for much of length; two parameroids, left hand one as long as trigonium, narrow, sinuate, right hand one much shorter, thick, thumb-like (Fig. 37). Tegmen a little shorter than penis, lobes well separated, long, thin, tips pointed (Fig. 37).

Etymology

Named after the State in which the specimens were found.

Notes

A relatively narrow, large, dark species from Victoria, recognised by the uniform dorsal colour, pale antennae bases, weak elytral flanging and long, thin, sinuate left parameroid (Fig. 37). The penis is unusually large and robust.

Acknowledgments

I would like to thank the following people whose help greatly improved the paper. The curators of the collections noted earlier for allowing me to examine specimens in their care; Howard Hamer for preparing the illustrations and transferring them to computer files ready for publication; Debbie Churches for improving the layout of the manuscript and Hiroyuki Yoshitomi for improving the manuscript, drawing my attention to the presence of *Ora* in the Australian fauna, and sending me a pre publication copy of his important Doctoral work on the Scirtidae of Japan.

References

- ARMSTRONG, J. W. T. 1953. On Australian Helodidae (Coleoptera). *Proceedings of the Linnean Society of New South Wales* **78**, 19–32.
- BLACKBURN, T. 1891. Notes on Australian Coleoptera with descriptions of new species. Part X. *Proceedings of the Linnean Society of New South Wales* **6**, 479–550.
- CARTER, H. J. 1935. Australian Coleoptera. Notes and new species. No 1X. *Proceedings of the Linnean Society of New South Wales* **60**, 179–193.
- KITCHENER, R. L. & ALLSOPP, P. G. 1987 *Prionocyphon niger* sp. n. (Coleoptera: Scirtidae) from water-filled tree holes in Australia. *Journal of the Australian Entomological Society*, **26**, 73–79.
- _____ & CALLAGHAN, C. 1982. The fauna of water-filled tree holes in box forest in Southeast Queensland. *Australian Entomological magazine* **8**, 61–70.
- LEA, A. M. 1919. Notes on some miscellaneous Coleoptera, with descriptions of new species.—Part V. *Transactions of the Royal Society of South Australia* **43**, 166–261.
- NYHOLM, T. 1972. Zur Morphologie und Function des Helodiden-Aedoeagus (Col.) *Entomologica Scandinavica* **3**, 81–119.
- _____ 2002. *Scirtes japonicus* Kiesenwetter and its allies, with descriptions of *Scirtes ussuriensis* n. sp. (Coleoptera, Scirtidae). *Entomologische Blätter* **98**, 49–60.
- PIC, M. 1956. Nouveaux Coleopteres de diverses families. *Annales Historico-Naturelles Musei Nationalis Hungarici* **7**, 71–92.
- WATERHOUSE, C. O. 1875–1882, Descriptions of new Coleoptera belonging to the families Psephenidae and Cyphonidae; *Cistula Entomologica*, **2**, 563–573.

**CHARACTERISTICS OF AN AUSTRALIAN POPULATION OF
PARAXONCHIUM ORTHODON (LOOF 1964) ALTHERR &
LOOF 1969, WITH A NOTE ON EVOLUTION AND
BIOGEOGRAPHY OF THE SUBFAMILY PARAXONCHIINAE
(NEMATODA, DORYLAIMIDA, APORCELAIMIDAE)**

*By M. HODDA**

Summary

Hodda, M. (2004). Characteristics of an Australian population of *Paraxonchium orthodon* (Loof 1964) Altherr & Loof 1969, with a note on evolution and biogeography of the subfamily Paraxonchiinae (Nematoda, Dorylaimida, Aporcelaimidae). Trans. R. Soc. S. Aust. 128(2), 169-174, 30 November, 2004.

The presence of *Paraxonchium orthodon* (Loof 1964) Altherr & Loof 1969 is recorded in Australia for the first time. The species has been found in NSW and Queensland to date. The morphometrics of specimens from the two localities show large differences, but the number of specimens is small, so these differences are inconclusive. The differences between the Australian and Venezuelan populations of *P. orthodon* are discussed and a cladistic analysis of the genera and species groups in the subfamily Paraxonchiinae is presented, resulting in *Paraxonchium rhamphionus* (Jairajpuri 1966) Altherr & Loof 1969 being placed in the "orthodon group" rather than, as previously, in the "laetificans group". Some biogeographic trends and the relationship of the subfamily with Aporcelaimidae or Qudsianematinae are also suggested by this analysis. The subfamily is basically Gondwanan in origin, but the genera *Parapalus* and *Paraxonchium* may be Laurasian, with a secondary radiation in Gondwana.

Key Words: first record, *Paraxonchium rhamphionus*, *Tendinema*, *Gopalus*, Aporcelaiminae.

CHARACTERISTICS OF AN AUSTRALIAN POPULATION OF *PARAXONCHIUM ORTHODON* (LOOF 1964) ALTHERR & LOOF 1969, WITH A NOTE ON EVOLUTION AND BIOGEOGRAPHY OF THE SUBFAMILY PARAXONCHIIINAE (NEMATODA, DORYLAIMIDA, APORCELAIMIDAE)

by M. HODDA*

Summary

HODDA, M. (2004) Characteristics of an Australian population of *Paraxonchium orthodon* (Loof 1964) Altherr & Loof 1969, with a note on evolution and biogeography of the subfamily Paraxonchiinae (Nematoda, Dorylaimida, Aporcelaimidae). *Trans. R. Soc. S. Aust.* 128(2), 169-174, 30 November, 2004.

The presence of *Paraxonchium orthodon* (Loof 1964) Altherr & Loof 1969 is recorded in Australia for the first time. The species has been found in NSW and Queensland to date. The morphometrics of specimens from the two localities show large differences, but the number of specimens is small, so these differences are inconclusive. The differences between the Australian and Venezuelan populations of *P. orthodon* are discussed, and a cladistic analysis of the genera and species groups in the subfamily Paraxonchiinae is presented, resulting in *Paraxonchium rhamphionus* (Jairajpuri 1966) Altherr & Loof 1969 being placed in the "orthodon group" rather than, as previously, in the "laetificans group". Some biogeographic trends and the relationship of the subfamily with Aporcelaimidae or Qudsianematinae are also suggested by this analysis. The subfamily is basically Gondwanan in origin, but the genera *Parapalus* and *Paraxonchium* may be Laurasian, with a secondary radiation in Gondwana.

KEY WORDS: first record, *Paraxonchium rhamphionus*, *Tendinema*, *Gopalus*, Aporcelaiminae.

Introduction

The subfamily Paraxonchiinae Dhanachand & Jairajpuri 1981 is a small, relatively homogeneous group of four genera and 17 species of free-living nematodes of the family Aporcelaimidae, order Dorylaimida. Five new species have been discovered and the subfamily reviewed within the last few years (Hodda *et al.* 1994, Siddiqi 1995). Loof & Zullini (2000) described a new genus from Costa Rica and transferred one genus containing a single species to the family Qudsianematidae. Andrassy (2001) transferred one species to the genus *Aporcelaimellus*. More recently, hitherto unknown specimens from Australia have been located and these appear to be from the known species *Paraxonchium orthodon* (Loof 1964) Altherr & Loof 1969. This paper presents a description of the Australian specimens, with a comparison with the other known population of *P. orthodon*. The specimens differ in a number of minor characters from the type population of *P. orthodon* in Venezuela (Loof 1964). A cladistic analysis of the subfamily Paraxonchiinae, together with Aporcelaimidae and Qudsianematinae is also presented to clarify the relationships within Paraxonchiinae and with prospective sister groups.

In the recent review of the subfamily, a number of evolutionary trends were noted (Hodda *et al.* 1994).

The location of *P. orthodon* in Australia allows a biogeographic interpretation of these evolutionary trends, with distinct Gondwana and Laurasian radiations. Such distinct biogeographic patterns have not been reported previously for nematodes.

Materials and methods

All measurements were along the midline, and used either an ocular micrometer (for straight structures less than 50µm) or a camera lucida drawing with map measuring wheel (for curved structures or greater than 50µm). Abbreviations for morphometric indices (a, a' etc) follow Hooper (1986).

The cladogram was constructed using PAUP4.0b10, using a branch and bound search, maximum parsimony, equal weighting of characters, the tree unrooted, 11 characters as listed (Figure 2), Aporcelaiminae and Qudsianematinae as outgroups, and six generic or group level taxa within Paraxonchiinae. Four equally parsimonious trees were found, with the tree presented being the consensus tree. Bootstraps of 1000 replicates were used to assess the support for each group, with ties broken randomly, using the mean character difference as the distance measure with the Permutation Tail Probability (PTP) test (Faith & Cranston 1991) (1000 randomisations, Branch & Bound (=exact) searches).

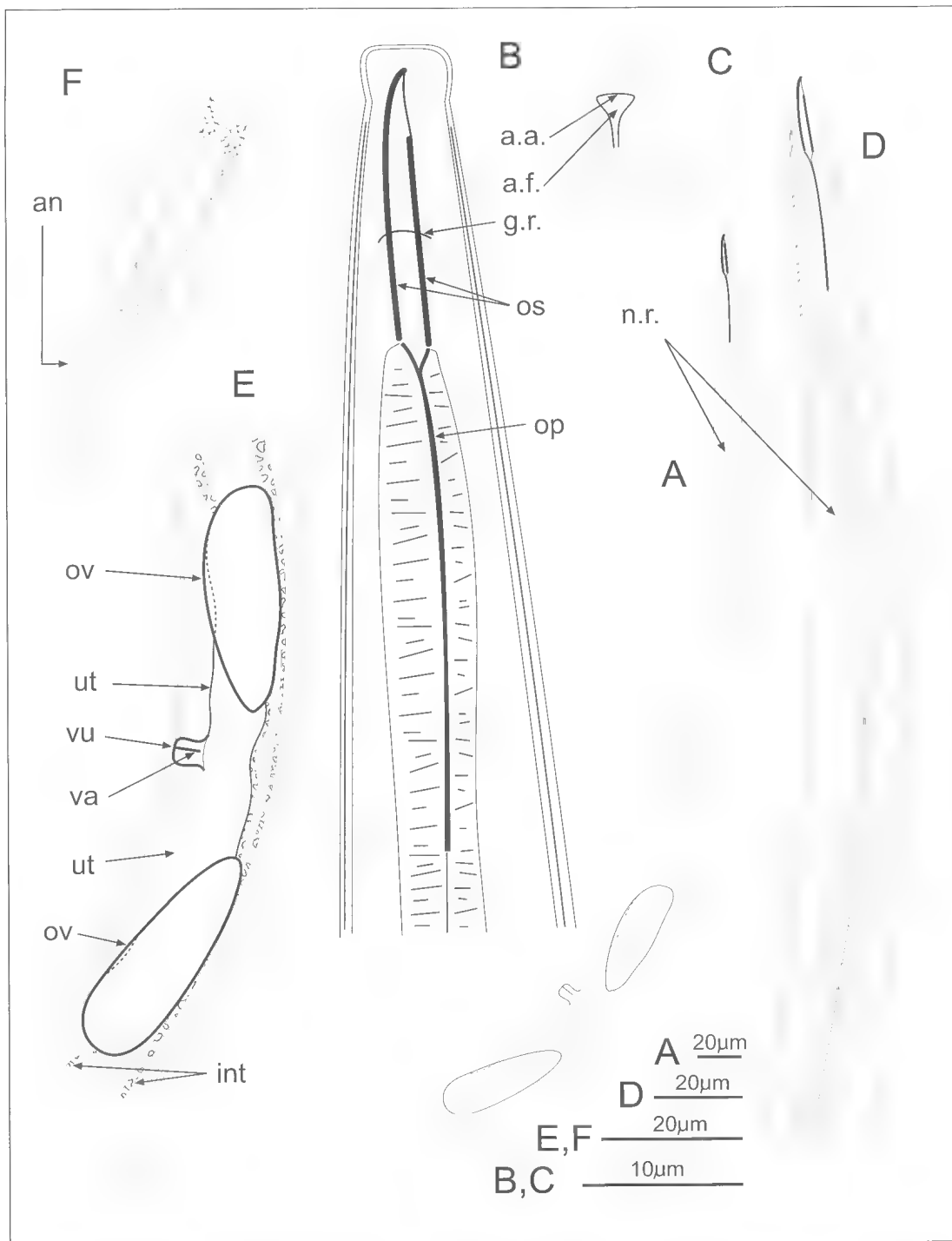


Fig. 1. Adult female of Australian population of *Paraxonchium orthodon*. A - whole body; B - anterior median lateral optical section; C - anterior lateral body surface; D - oesophageal region; E - reproductive system; F - tail. Structures indicated by arrows as follow: a.a. = amphidial aperture, a.f. = amphidial fovea, an = anus, g.r. = guide ring, int = intestine, n.r. = nerve ring, os = odontostyle, op = odontophore, ov = ovary, ut = uterus, va = vagina, vu = vulva.

TABLE 1. *Measurements of Australian specimens of Paraxonchium orthodon.*

measure in μm or morphometric index (Hooper 1986)	NSW specimen	Queensland specimens range
number of specimens	1	3
length of odontostyle	17	17-18
diameter of odontostyle	2	2
length of odontophore	33	30-37
Distance from anterior to constriction	3	3
Distance from anterior to guide ring	12	11-13
length of oesophagus	225	191-242
diameter at base of lips	6	4-5
diameter at oesophago-intestinal junction	32	13-24
maximum diameter	37	14-24
distance from anterior to vulva	297	284-415
length of tail	33	28-30
diameter at anus/cloaca	17	10-14
L	563	434-633
L'	530	406-603
A	15.2	27.2-33.3
a'	14.3	25.9-33.2
B	2.5	2.3-3.3
b'	2.4	2.1-3.2
C	16.9	15.7-21.1
c'	1.9	2.1-2.6
V	0.53	0.65-0.67
V'	0.56	0.68-0.70
ratio of length to diameter of odontostyle	9	9
ratio of body diameters at lip base and oesophago-intestinal junction	5.3	4.2-4.4

Description of Australian specimens of *P. orthodon*

Material examined

QM (Queensland Museum, Brisbane) G 203090 (2 adult females), Camp Cable Qld Australia (27° 48' S 153° 06' E), coll: R.C. Colbran, July 1967, soil around *Casuarina* sp. and *Acacia* sp.;

QM G 203091 (1 adult female & one juvenile), Cooroy Qld Australia (26° 25' S 152° 55' E), coll: C. Banner, August 1967, soil;

QM G 203092 (1 adult female), Maclean NSW Australia (29° 28' S 153° 12' E), coll: unknown, August 1963, soil.

Method of fixation is unrecorded for all specimens, which are currently stored in anhydrous glycerol on standard microscope slides, having been remounted in 1992.

Description

Table 1, Fig. 1.

Body vermiform, small, greatly narrowed towards anterior extremity. Cuticle conspicuously layered,

thick (about 1.5 μm), thicker towards ends of body, with fine transverse annulations. Sub-cuticle not annulated. Lateral hypodermal chords without conspicuous glands. Anterior face rounded. A rounded, shallow constriction about one body diameter (at the constriction) from anterior, circumference rounded convex anterior to constriction, without longitudinal division. Amphidial aperture unsclerotized, close to level of constriction, slit-like, about half as wide as head. Amphidial fovea with inflexion, not sclerotized, without median support, not duplex. Odontostyle of medium thickness, strongly cuticularized, with aperture of about 3 μm length or 25% of length of odontostyle, with broad central lumen and anterior ventral surface bent towards dorsal side of body. Odontophore arcuate, weakly sclerotized, rod-like. Guiding ring unsclerotized, single, not plicate. Oesophagus expanded in posterior 40%, muscular throughout, nerve ring located 30-50% of total oesophageal length from anterior, with 3 gland cells and conoid cardia at oesophago-intestinal junction. Prerectum short, about 2 anal body diameters or 50 μm long. Rectum about 1 anal body diameter or 12 μm long, straight, without rectal glands, with distinct cuticular indentation at anus. Female reproductive system didelphic, amphidephic, branches approximately equal in length, reflexed for about half length to the left side for both ovaries, without sperm. Vulva a transverse slit, sclerotized, without flaps or disc-like structure between vagina and cuticle. Vagina sclerotized over most of length, straight, perpendicular to body wall, 10 – 14 μm long, with narrow lumen at junction with uterus, without muscular sheath. Tail conoid, curved ventrally, terminus rounded, with cuticular thickening.

Discussion

Differences between Australian and Venezuelan populations

The Australian specimens are similar to those from Venezuela and conform with the original description in most features except for the odontostyle and odontophore lengths and the morphometric indices a, b and V, which differ in range while still all overlapping.

Differences between Australian specimens

The observed wider range of the morphometric index "a" in the Australian population of *P. orthodon* compared to that for the Venezuelan population raises the possibility that the Australian population is in fact two separate and distinct taxa. One of these is probably *P. orthodon*, consisting of the three Queensland specimens which had values of the morphometric index "a" between 27 and 33. The

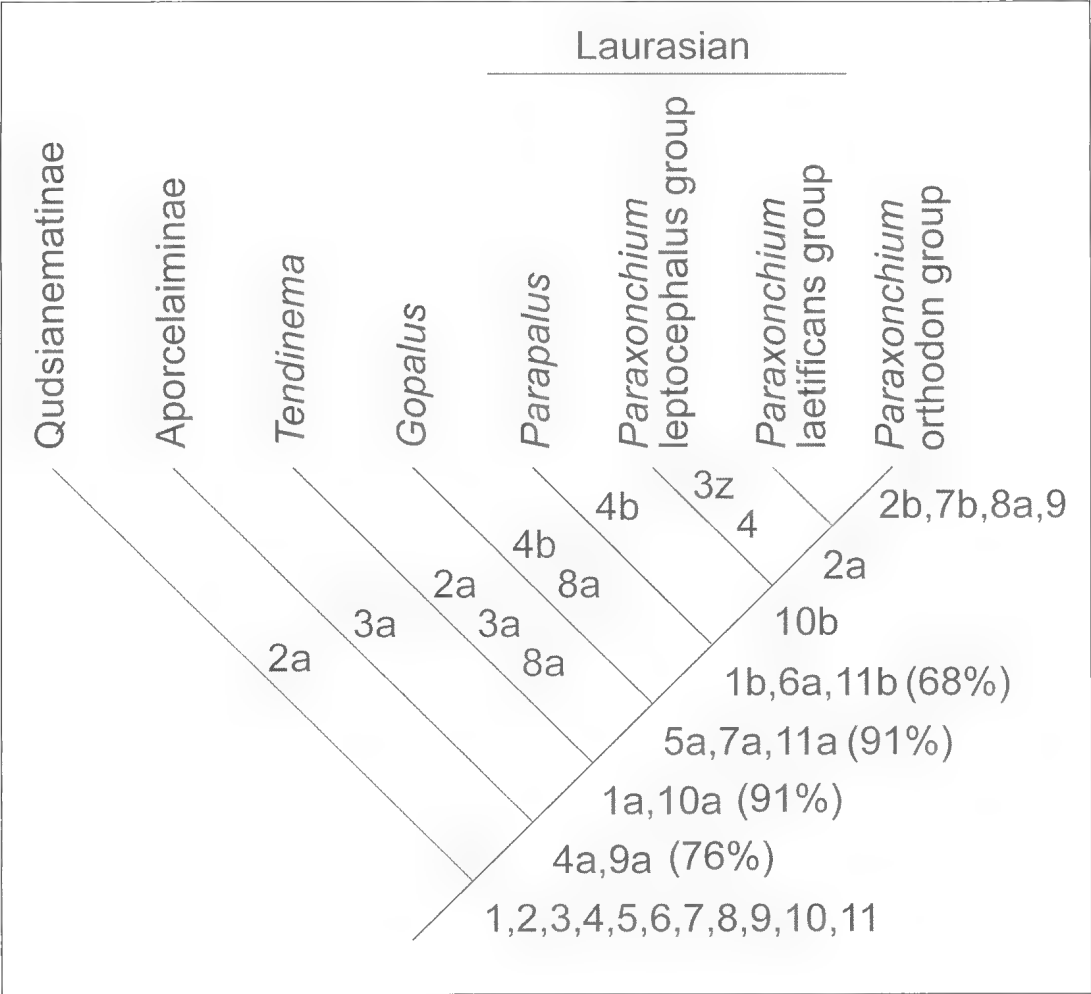


Fig. 2. Cladogram of relationships between genera and species groups within the subfamily Paraxonchiinae. Numbers refer to characters used in analysis and letters to state changes after each node, thus the apomorphies characterising each named from the other groups arising from the same node are presented on the branch below the name. All characters were ordered and numbers without a letter refer to the initial state. 1 = narrowing of head (initial state narrowed to more than 0.40; a - narrowed to 0.33-0.40; b - narrowed to less than 0.33); 2 = body size (initial state large; a - medium size; b - small); 3 = diameter of odontostyle (initial state medium; z - small; a - large); 4 = odontostyle length (initial state medium; a - long; b - very long); 5 = odontostyle bend on ventral side (initial state absent; a - present); 6 = odontostyle bend on dorsal side (initial state absent; a - present); 7 = odontostyle aperture length (initial state large; a - small; b - very small); 8 = head constriction (initial state present; a - reduced); 9 = tail length (initial state long; a - short); 10 = lips (initial state separate; a - partly amalgamated; b - amalgamated); 11 = cardiac glands (initial state absent; a - weakly developed; b - well developed). Percentages in parentheses represent the support for groupings from bootstrap analyses and PTP tests greater than 50% ($P=0.004$). All taxa not indicated as Laurasian are Gondwanan, with the exception of *P. loofi* in the *Paraxonchium* "orthodon group".

other specimen, from NSW, had a value of 15. This observation alone does not carry much weight because the index "a" is often unreliable for systematic purposes at species level (Geraert 1978, Geraert & Jacob 1981).

The large difference in the range of the parameter V has more influence in suggesting that the NSW and Queensland specimens may be different taxa. This parameter is generally the most reliable morphometric characteristic (Geraert 1978, Geraert & Jacob 1981).

Despite these apparent differences between the specimen from NSW and those from Queensland, all the specimens are provisionally assigned to a single species because the number of specimens was insufficient to properly evaluate variability within populations from any locality. The single specimen from Maclean may represent a highly aberrant individual.

Likewise, the differences between the Australian and Venezuelan specimens of *P. orthodon* seem insufficient to justify description of any new taxa. The specimens are similar in most respects and given the small number of specimens of *P. orthodon* known (4 from Australia, 6 from Venezuela), variability cannot be evaluated meaningfully.

In any future considerations of the genus *Paraxonchium*, the variability in the length of odontostyle needs to be investigated. Length of odontostyles varies by only about 1 µm in most species of the subfamily, which is the measurement error (Hodda *et al.* 1994). The specimens of *P. orthodon* from Australia are no exception. However, the variability in the odontostyle length of the Venezuelan population of *P. orthodon* is somewhat larger. It is possible that some of these specimens may be different taxa. At least three species are found sympatrically in Africa (Hodda *et al.* 1994, Siddiqi 1995).

Evolutionary and biogeographic relationships within the subfamily Paraxonchiinae

The subfamily Paraxonchiinae currently consists of three or four genera: *Paraxonchium* Krall 1958 (13 species), *Gopalus* Khan, Jairajpuri & Ahmad 1987 (one species), *Tendinema* Siddiqi 1995 (two species) and *Parapalus* Loof & Zullini 2000 (one species). The genera *Tendinema* and *Parapalus* were added to the subfamily after the review by Jairajpuri & Ahmad (1992), and *Gopalus* was removed (Loof & Zullini 2000). In addition, there are 3 informal species groups within the genus *Paraxonchium*, each representing separate evolutionary trends (Hodda *et al.* 1994). These evolutionary trends are clarified by the addition of the recently described taxa, so that a consistent cladogram of relationships may be constructed using the characters suggested by Hodda *et al.* (1994) (Figure 2).

The cladistic analysis gives support to the holophyly of Paraxonchiinae as originally defined (including *Tendinema*, *Gopalus* and *Parapalus*). The shared apomorphies are narrowing of the anterior of the body to less than 40% of the diameter at the posterior of the oesophagus, and at least partly amalgamated lips. This clade is more closely related to Aporcelaimidae than Qudsianematinae, contrary to the suggestion of Loof & Zullini (2000). There is equally strong support for a clade of the genera

except *Tendinema* in Paraxonchiinae, sharing the apomorphies of odontostyle with the ventral surface deviated dorsally near the anterior end, the odontostyle aperture reduced, and cardiac glands present. There is also some support for a clade of the genera *Parapalus* and *Paraxonchium*, sharing the apomorphies of further narrowing of the anterior of the body (to less than 33% of the diameter at the posterior of oesophagus), the dorsal side of the odontostyle deviated dorsally near the anterior end and better developed cardiac glands. Within the clade of *Parapalus* and *Paraxonchium*, however, support for any of the subdivisions is weak, although there are apomorphies for all clades except the laetificans group of *Paraxonchium*.

Thus the main conclusions are:

1. *Tendinema*, *Gopalus*, *Parapalus* and *Paraxonchium* form a holophyletic subfamily Paraxonchiinae;
2. the subfamily is related more closely to Aporcelaiminae than Qudsianematinae, and so is within the family Aporcelaimidae;
3. the "laetificans group" of *Paraxonchium* is not supported by any apomorphies;
4. the genus *Parapalus* is closely related to *Paraxonchium*;
5. *P. rhamphionus* (Jairajpuri 1966) Altherr & Loof 1969 is best placed in the "orthodon group" since it has a small body, very small odontostyle aperture, little or no constriction at the anterior of the body and a long tail (Hodda *et al.* 1994), which are all synapomorphies of the "orthodon group" as identified by the cladistic analysis. This is contrary to its earlier placement in the "laetificans group" (Hodda *et al.* 1994).

This scheme is contrary to suggestions that the subfamily may be paraphyletic (Siddiqi 1995, Zullini & Loof 2000).

The cladogram also suggests a consistent biogeographic pattern (Figure 2). This is one of the few such patterns found in free-living nematodes. The subfamily is overwhelmingly Gondwanan, with all members of the genera *Gopalus* (one species), *Tendinema* (two species), and the "orthodon group" of *Paraxonchium* (eight species) found in that region. The "leptocephalus" (one species) and "laetificans" (four species) groups are European, with a single species found in North America together with *Parapalus* (one species). The only exception to this pattern is *P. loofi*, from the otherwise Gondwanan "orthodon group," which is found in the Netherlands.

The most parsimonious biogeographic explanation of the observed distribution is that *Tendinema* and *Gopalus* evolved in Gondwana, but that the clade of *Paraxonchium* and *Parapalus* evolved in Laurasia,

with the orthodon group returning to Gondwana. Under this scheme *P. loofi* is the oldest lineage of the group. The only alternative is four separate dispersals into Laurasia, by *Parapalus*, the "leptocephalus group", the "laetificans group", and by *P. loofi* from the "orthodon group".

More investigation of the dispersal and biogeography of free-living nematodes may yield insights into nematode evolution at the species and subgeneric levels. Quarantine, pest management and systematics of nematodes may all benefit from such studies by elucidating some of the potential mechanisms of soil nematode dispersal, including their frequency and whether they are linked to particular systematic or ecological groups. The subsequent evolutionary radiation (or lack thereof)

and whether linked to systematic or ecological groups, is also of particular interest for pest management.

Acknowledgments

I thank Dr L. Cannon, Queensland Museum, Brisbane, for the loan of specimens and for allowing me to explore the Queensland Museum specimen database, and Ms E. Stewart (CSIRO Entomology, Canberra) for the electronic drawing of the figures. I am grateful to Dr J Trueman (Australian National University) for performing the cladistic analysis. I also thank Drs P Cranston and J Curran (CSIRO Entomology, Canberra) and Dr P Loof (Wageningen Agricultural University) for critical comments on a draft.

References

- ALTHIERR, E. & LOOF, P. A. A. (1969) *Paraxonchium* Krall 1958 a valid generic name. *Nematologica* **15**, 431-432.
- ANDRASSY, I. (2001) A taxonomic review of the genera *Aporcelaimus* Thorne & Swanger, 1936 and *Metaporcelaimus* Lordello, 1965 (Nematoda, Aporcelaimidae). *Opuscula Zoologica* (Budapest) **33**, 7-47.
- DIANACHAND, C. & JAIRAJPURI, M. S. (1981) Some observations on the genus *Paraxonchium* (Dorylaimida) with description of a new species from Manipur, India. *Ind. J. Nematol.* **11**, 61-66.
- FAITH, D. P. & CRANSTON P. S. (1991) Could a cladogram this short have arisen by chance alone? On permutation tests for cladistic structure. *Cladistics* **7**, 1-28.
- GERAERT, E. (1978) Morphometric relations in nematodes. *Nematologica* **14**, 171-183.
- & JACOBS, L. (1981) Morphometric comparison of the Dorylaimida species (Nematoda). *Meded. Fac. Landbouww. Rijksuniv. Gent* **46**, 721-727.
- HODDA, M., BLOEMERS, G. F., WANLESS, F. R., SIDDIQI, M. R. (1994) Four new species of the genus *Paraxonchium* Krall 1958 (Nematoda, Dorylaimida, Aporcelaimidae, Paraxonchiinae), with a review of the subfamily Paraxonchiinae Dhanachand & Jairajpuri 1981. *Afro-Asian J. Nematol.* **4**, 165-176.
- HOOPER, D.J. (1986b). Drawing and measuring nematodes. pp 87-94 *In* Southey, J.F. (Ed) "Laboratory methods for work with plant and soil nematodes" 6th edn. (HMSO. London).
- JAIRAJPURI, M. S. & AHMAD, W. (1992) "Dorylaimida: free-living, predaceous and plant-parasitic nematodes" (Oxford & IBH Publishing, New Delhi).
- LOOF, P. A. A. (1964) Free-living and plant-parasitic nematodes from Venezuela. *Nematologica* **10**, 201-300.
- & ZULLINI, A. (2000) Freelifing nematodes from nature reserves in Costa Rica. 1. Dorylaimina. *Nematology* **2**, 605-633.
- SIDDIQI, M. R. (1995) Nematodes of tropical rainforests. 5. Seven new genera and forty two new species of dorylaims. *Afro-Asian J. Nematol.* **5**, 72-109.

**CESTODE PARASITES OF TREE KANGAROOS (DENDROLAGUS
SPP.: MARSUPIALIA), WITH THE DESCRIPTION OF
TWO NEW SPECIES OF PROGAMOTAENIA
(CESTODA: ANOPLOCEPHALIDAE)**

By I. BEVERIDGE & P. M. JOHNSON†*

Summary

Beveridge, I. & Johnson, P. M. (2004) Cestode parasites of tree kangaroos (*Dendrolagus* spp.: Marsupialia), with the description of two new species of *Progamotaenia* (Cestoda: Anoplocephalidae). *Trans. R. Soc. S. Aust.* 128(2) 175-185, 30 November, 2004.

Two new species of *Progamotaenia* Nybelin, 1917 are described from tree kangaroos: *P. dendrolagi* sp. n. from the small intestines of *Dendrolagus bennettianus* De Vis, 1887 and *D. lumholtzi* Collett, 1884 from north-eastern Queensland, and *P. irianensis* sp. n. from the intestine of *D. dorianus* Ramsay, 1883 from Irian Jaya. A re-description of *P. wallabiae* Beveridge, 1985, from *D. dorianus*, a new host for the genus, is given. *P. dendrolagi* is highly host specific, being restricted to tree kangaroos, while *P. wallabiae* occurs also in scrub wallabies of the genus *Dorcopsis* Schlegel & Mueller, 1842 from the island of New Guinea. The phylogenetic relationships of *P. irianensis* with congeners are not clear. The life cycles of the cestodes are discussed in relationship to the arboreal nature of the hosts and the presumed use of terrestrial oribatoid mites as intermediate hosts.

Key Words: Cestoda, Anoplocephalidae, *Progamotaenia*, *Dendrolagus*, tree kangaroos, Macropodidae, new species.

CESTODE PARASITES OF TREE KANGAROOS (*DENDROLAGUS* SPP.: MARSUPIALIA), WITH THE DESCRIPTION OF TWO NEW SPECIES OF *PROGAMOTAENIA* (CESTODA: ANOPOLOCEPHALIDAE)

by I. BEVERIDGE* & P. M. JOHNSON†

Summary

BEVERIDGE, I. & JOHNSON, P. M. (2004). Cestode parasites of tree kangaroos (*Dendrolagus* spp.: Marsupialia), with the description of two new species of *Progamotaenia* (Cestoda: Anoplocephalidae). *Trans. R. Soc. S. Aust.* 128(2), 175-185, 30 November, 2004.

Two new species of *Progamotaenia* Nybelin, 1917 are described from tree kangaroos: *P. dendrolagi* sp. n. from the small intestines of *Dendrolagus bennettianus* De Vis, 1887 and *D. lumholtzi* Collett, 1884 from north-eastern Queensland, and *P. irianensis* sp. n. from the intestine of *D. dorianus* Ramsay, 1883 from Irian Jaya. A re-description of *P. wallabiae* Beveridge, 1985, from *D. dorianus*, a new host for the genus, is given. *P. dendrolagi* is highly host specific, being restricted to tree kangaroos, while *P. wallabiae* occurs also in scrub wallabies of the genus *Dorcopsis* Schlegel & Mueller, 1842 from the island of New Guinea. The phylogenetic relationships of *P. irianensis* with congeners are not clear. The life cycles of the cestodes are discussed in relationship to the arboreal nature of the hosts and the presumed use of terrestrial oribatoid mites as intermediate hosts.

KEY WORDS: Cestoda, Anoplocephalidae, *Progamotaenia*, *Dendrolagus*, tree kangaroos, Macropodidae, new species.

Introduction

The helminth parasites of tree kangaroos (*Dendrolagus* spp.) are poorly known (Spratt *et al.* 1991), with most parasite records being based upon opportunistic collecting involving one or two host specimens. A study of a series of seven *D. lumholtzi* Collett, 1884, from north-eastern Queensland (Beveridge *et al.* 1992) revealed a relatively depauperate helminth community, a fact attributed to the arboreal nature of the host compared with a predominantly terrestrial mode of transmission of most of the helminth parasites of macropodid marsupials (Beveridge & Spratt 1996). A recent examination of a limited number of specimens of *Dendrolagus* spp. from Irian Jaya (Flannery *et al.* 1996) has suggested that that some species may harbour a more complex community of helminths than described in previous publications, with some species of helminths occurring in considerable numbers.

Although the cestode genus *Progamotaenia* Nybelin, 1917 is abundant in many macropodid species (Beveridge 1976, 1978b, 1980, 1985; Beveridge & Thompson 1979; Turni & Smales 1999; Beveridge & Turni 2003), records of the genus from tree kangaroos are few. Löser (1965) in a study of the histology of the female genital glands of cestodes reported the occurrence of *P. zschokkei* (Janicki,

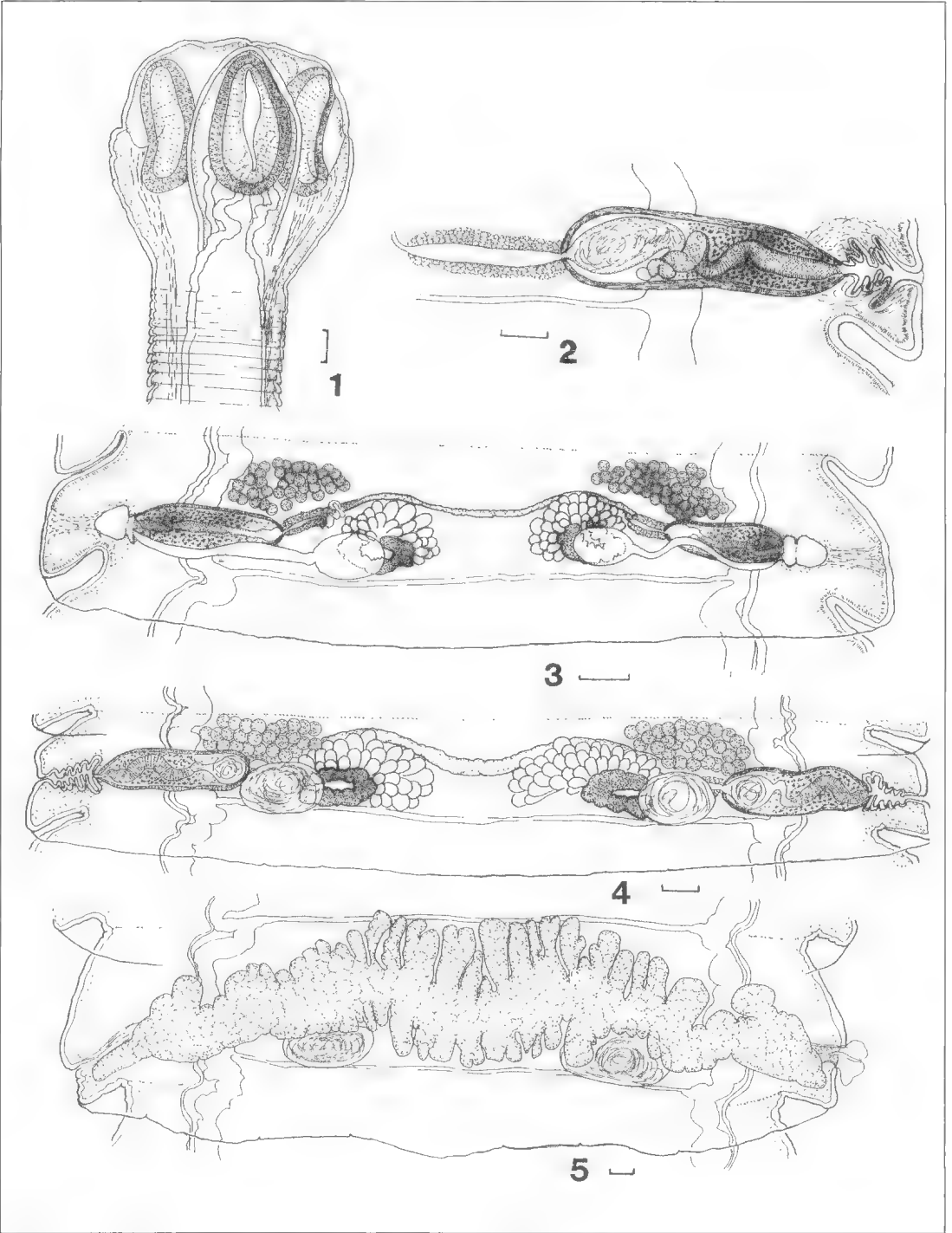
1906) in *D. ursinus* Mueller, 1840 from a European zoo, while Spratt *et al.* (1991) and Beveridge *et al.* (1992) reported *P. zschokkei* from *D. lumholtzi* in north-eastern Queensland. Spratt *et al.* (1991) also reported the presence of an undescribed species of *Progamotaenia* in *D. bennettianus* De Vis, 1887 from Queensland, while Flannery *et al.* (1996) reported two species of cestodes, *P. wallabiae* Beveridge, 1985 and *P. cf. dorcopsis* Beveridge, 1985, from *D. dorianus* Ramsay, 1883 from Irian Jaya. The fragmentary data available to date therefore suggest that tree kangaroos might harbour a number of species of anoplocephalid cestodes.

In this report, the species of cestodes present in tree-kangaroos are reviewed and two new species are described, one from northern Queensland and one from Irian Jaya. A further species found in tree kangaroos, but formerly known only from scrub wallabies, *P. wallabiae*, is re-described and the associations between hosts and parasites are considered.

Materials and Methods

Cestodes obtained were from animals which had been collected for other purposes. Specimens of *D. lumholtzi* were obtained as road-kills and frozen prior to examination. At autopsy, cestodes were washed in water and fixed in AFA (Pritchard & Kruse 1982). Individuals of *D. dorianus* were collected for museum specimens and the entire gastrointestinal tracts had been fixed in formalin prior to examination. Cestodes were removed,

* Department of Veterinary Science, University of Melbourne, Parkville Vic. 3052.
† Queensland Parks and Wildlife Service, Townsville, Qld 4810.



Figs 1-5. *Progamotaenia dendrolagi* sp. nov. 1. Scolex. 2. Cirrus sac and genital atrium. 3. Premature segment prior to patency of genital atria, showing vaginæ extending to atrial primordia. 4. Mature segment showing patency of atria, sperm in seminal receptacles and disappearance of vaginæ. 5. Pregravid segments showing single uterus with numerous anterior and posterior diverticula. All illustrations from holotype. Scale bars = 0.1 mm.

washed in water and stored in 70% ethanol.

Cestodes were stained in Celestine blue, dehydrated in ethanol and cleared in methyl salicylate. In thick or dark specimens, the cleared cestodes were allowed to harden in methyl salicylate and the tegument and longitudinal muscle layers removed with fine forceps to reveal the medullary organs. In some instances, hand-cut transverse sections were prepared of mature or gravid segments. Cestodes were mounted in Canada balsam. Parts of new species of cestodes were embedded in paraffin, serially sectioned at a thickness of 10 µm and the sections stained with haematoxylin and eosin.

Drawings were made using a drawing tube attached to an Olympus BH microscope. Measurements were made with an ocular micrometer or a ruler and are presented throughout the paper in millimetres as the mean followed, in parentheses, by the range and the numbers of measurements made (n=).

Type specimens have been deposited in the South Australian Museum, Adelaide (SAM).

Host nomenclature follows Groves & Flannery (1989), Spratt *et al.* (1991) and Flannery *et al.* (1996).

***Progamotaenia dendrolagi* sp. nov.**
(FIGS 1-5)

Synonyms: *Progamotaenia* sp. nov. of Spratt *et al.* 1991, p. 62 (*Dendrolagus bennettianus*); *Progamotaenia zschokkei* (Janicki, 1906) of Spratt *et al.* (1991), Beveridge *et al.* (1992) (*Dendrolagus lumholtzi*).

Holotype: From *Dendrolagus bennettianus* De Vis, 1887, Bargoo Creek, Mount Windsor State Forest, Queensland (23° 38' S 141° 40' E), 19.ix.1986, coll. G. Richards, SAM AHC 22654.

Paratypes: From *Dendrolagus lumholtzi* Collett, 1884: Queensland: 3 specimens, Mount Baldy State Forest, (17° 17' S 145° 27' E), 7.viii.1991, coll. P.M. Johnson (SAM AHC 28511-3); 1 specimen, Herberton (17° 23' S 145° 23' E), 1.i.1990, coll. P.M. Johnson (SAM AHC 28514-5); fragments of 1 specimen, Malanda (17° 21' S 145° 36' E), 1993, coll. P.M. Johnson (SAM AHC 28516); 2 specimens, Palmerston (17° 32' S 145° 40' E), coll. 16.xii.1976, P.M. Johnson (SAM AHC 12231, 22132), (serial sections SAM AHC 28517) (10 slides).

Site in host: Small intestine

Description

Small cestodes, holotype 54 long, 4 wide,

composed of 170 segments; paratypes 28–60 (43, n = 3) long, width 4–6 (5, n = 3). Scolex prominently 4-lobed, 0.76 in diameter in holotype, 0.74–1.21 (1.04, n = 4) in diameter in paratypes, with oval suckers 0.39–0.42 (0.41, n = 3) long by 0.17–0.24 (0.21, n = 3) wide in holotype, 0.30–0.38 (0.35, n = 10) long by 0.20–0.33 (0.27, n = 10) wide in paratypes. Neck absent or very short. Segments transversely elongate, with prominent velum overhanging subsequent segment; posterior border of velum straight or slightly undulate; as segments increase in size along strobila, velum covers $\frac{1}{2}$ to $\frac{2}{3}$ of succeeding segment. Premature segments 0.27–0.31 (0.29, n = 5) long, 1.56–1.01 (1.72, n = 5) wide, velum 0.05–0.13 (0.09, n = 5) long in holotype; 0.28–0.44 (0.37, n = 5) long, 2.57–3.13 (2.95, n = 5) wide, velum 0.20–0.24 (0.22, n = 5) long in paratypes. Mature segments 0.29–0.32 (0.30, n = 5) long, 1.95–2.65 (2.39, n = 5) wide, velum 0.08–0.10 (0.09, n = 5) long in holotype; 0.39–0.47 (0.42, n = 5) long, 3.04–3.90 (3.50, n = 5) wide, velum 0.17–0.26 (0.22, n = 5) long in paratypes. Pregravid segments 0.47–0.61 (0.52, n = 5) long, 3.12–3.82 (3.56, n = 5) wide, velum 0.19–0.26 (0.23, n = 5) in holotype; 0.35–0.66 (0.51, n = 5) long, 4.91–5.93 (5.41, n = 5) wide, velum 0.27–0.43 (0.35, n = 5) long in paratypes. Genital pores paired, in middle of lateral segment margins. In premature segments, genital atrium circular in dorso-ventral views, not patent; in mature segments, genital atrium consists of narrow central passage with numerous anterior and posterior diverticula; when everted, cirrus extrudes from genital papilla formed by everted genital atrium. Cirrus sac elongate, with thick muscular wall, extending beyond osmoregulatory canals into medulla. Cirrus sac in holotype 0.37–0.45 (0.41, n = 5) long by 0.10–0.14 (0.12, n = 5) in mature segments, 0.58–0.68 (0.63, n = 5) long by 0.16–0.20 (0.17, n = 5) wide in pregravid segments; in paratypes 0.39–0.61 (0.50, n = 5) long by 0.12–0.16 (0.14, n = 5) wide in mature segments, 0.51–0.64 (0.58, n = 5) long by 0.17–0.21 (0.19, n = 5) wide in pregravid segments. Cirrus armed distally with numerous, regularly-arranged spines; width of cirrus diminishes proximally with similar reduction in size of spines; most proximal region of cirrus unarmed, leads into sub-circular or fusiform internal seminal vesicle; cirrus sac between distal extremity and internal vesicle filled with densely-staining gland cells. Internal seminal vesicle in holotype 0.09–0.16 (0.12, n = 5) long by 0.08–0.09 (0.08, n = 5) in mature segments, 0.16–0.28 (0.20, n = 5) long by 0.12–0.16 (0.13, n = 5) wide in pregravid segments; in paratypes 0.12–0.18 (0.16, n = 5) long by 0.08–0.10 (0.09, n = 5) in mature segments, 0.12–0.20 (0.19, n = 5) long by 0.08–0.20 (0.12, n = 5) wide in pregravid segments.

External seminal vesicle clearly visible only in post-mature segments, elongate, extends medially and anteriorly from proximal pole of cirrus sac, covered with layer of glandular cells; external seminal vesicle 0.21 – 0.27 (0.25, $n = 5$) long by 0.05 – 0.08 (0.07, $n = 5$) in holotype, 0.31 – 0.47 (0.38, $n = 5$) long by 0.07 – 0.12, $n = 5$) wide in paratypes; vas deferens arises from proximal pole of external seminal vesicle. Testes invariably arranged in two completely separate groups extending from ventral osmoregulatory canals to level of seminal receptacle; 3 to 8 rows of testes in antero-posterior direction; 3 to 4 layers in dorso-ventral plane; 36 – 55 (43, $n = 5$) per group in holotype; 35 – 47 (43, $n = 5$) per group in paratypes. Testis diameter 0.043 – 0.059 (0.050, $n = 10$) in holotype, 0.055 – 0.070 (0.062, $n = 10$) in paratypes.

Vagina tubiform, opening to genital atrium posterior to cirrus sac; connection between vagina and genital atrium clearly visible in premature segments prior to patency of genital atrium; once genital atrium becomes patent, distal vagina atrophies and becomes inapparent. Vagina leads to ovoid seminal receptacle on posterior margin of segment medial to cirrus sac; receptacle empty prior to patency of genital atrium, filled with sperm immediately after genital atrium becomes patent. Seminal receptacle in holotype 0.21 – 0.27 (0.24, $n = 5$) long by 0.15 – 0.20 (0.16, $n = 5$) wide in mature segments, 0.20 – 0.41 (0.34, $n = 5$) long by 0.16 – 0.27 (0.21, $n = 5$) wide in gravid segments; in paratypes 0.26 – 0.51 (0.37, $n = 5$) long by 0.16 – 0.27 (0.21, $n = 5$) wide in mature segments, 0.37 – 0.55 (0.48, $n = 5$) long by 0.12 – 0.23 (0.19, $n = 5$) wide in gravid segments. Ovary flabelliform, with oöcapt near medial pole of seminal receptacle; ovary on ventral aspect of medulla. Ovary in holotype 0.16 – 0.23 (0.20, $n = 5$) long, 0.31 – 0.45 (0.40, $n = 5$) wide; in paratypes 0.21 – 0.27 (0.23, $n = 5$) long, 0.37 – 0.59 (0.44, $n = 5$) wide. Vitellarium horseshoe-shaped, posterior and dorsal to oöcapt; in holotype 0.08 – 0.10 (0.09, $n = 5$) long by 0.20 – 0.23 (0.21, $n = 5$) wide; in paratypes 0.09 – 0.12 (0.11, $n = 5$) long by 0.21 – 0.28 (0.23, $n = 5$) wide. Mehlis' gland spherical, visible only in paratypes, situated in U formed by vitellarium, 0.09 – 0.12 (0.11, $n = 5$) in diameter. Uterus single in each segment situated anterior to ovaries; immature uterus tubiform, extending laterally only to proximal poles of cirrus sacs; in pregravid segments, uterus develops numerous anterior and posterior diverticula, extends laterally, dorsal to osmoregulatory canals, almost reaching postero-lateral corners of segments. No gravid specimens present; eggs in all available specimens immature. Paired osmoregulatory canals present; ventral canal larger, 0.02 – 0.17 in diameter; dorsal canal external to ventral, much narrower, 0.04

– 0.11 in diameter; transverse canal, 0.02 – 0.04 in diameter connects ventral canals at posterior margin of each segment. Inner longitudinal musculature weakly developed, consisting of elongate bundles of up to 12 muscle fibres in medial zone of cortex; transverse muscles form distinct band at cortico-medullary junction; dorso-ventral muscles prominent, arranged as numerous individual fibres crossing cortex and medulla.

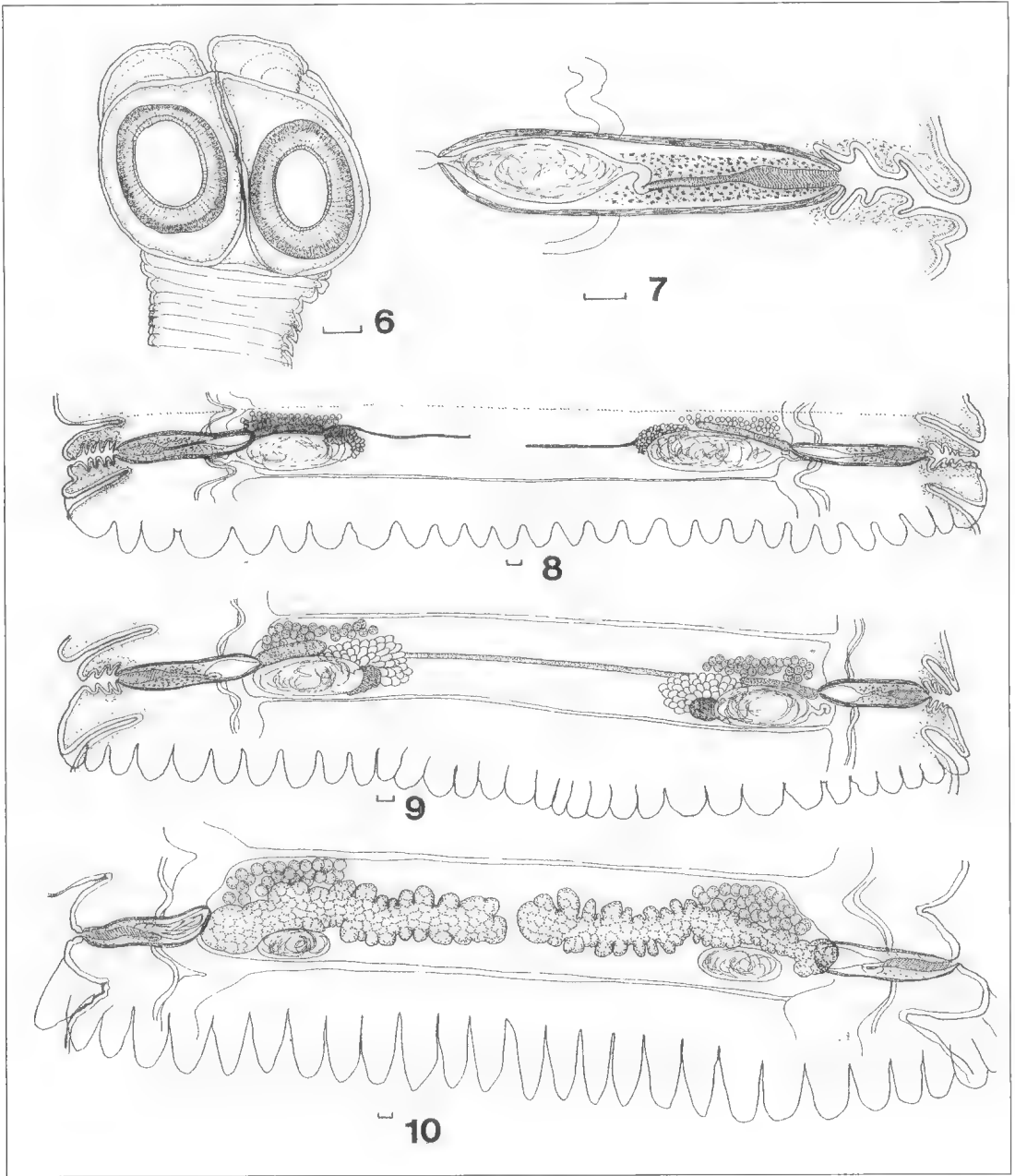
Development of segments in holotype : genitalia fully formed by segment 55; genital atrium becomes patent and sperm appears in seminal receptacle in segment 70; uterus commences filling in segment 80; ovary involuted with remnants of vitellarium still present by segment 120; anterior and posterior diverticula of uteri present in segment 125; total number of segments 170.

Remarks

Most species of *Progamotaenia* possess two uteri per segment. Schmidt (1986) separated those species with a single uterus into two genera *Adelataenia* Schmidt, 1986 and *Wallabicestus* Schmidt, 1975, neither of which was accepted by Beveridge (1994). The species described above is therefore allocated to *Progamotaenia* based on the definition of the genus by Beveridge (1994) which includes species with both single and paired uteri. Species with a single uterus are *P. effigia* Beveridge, 1976, *P. ewersi* (Schmidt, 1975), *P. villosa* (Lewis, 1914) and *P. zschokkei* (Janicki, 1906).

The specimens described above differ from *P. villosa* and *P. zschokkei* in lacking a distinctly fimbriated velum and differ from *P. effigia* and *P. ewersi* in having the testes distributed in two distinct groups rather than in a single continuous band across the medulla. In addition they differ from *P. effigia* in having an external seminal vesicle covered with glandular cells (lacking in *P. effigia*) and in infecting the small intestine rather than the bile duct, as is the case with *P. effigia*. They further differ from *P. ewersi* in lacking a distal vagina surrounded by prominent layers of glandular cells and in having the vagina atrophy following insemination of the proglottis. The specimens therefore represent a new species for which the name *P. dendrolagi* is proposed.

The description of *P. dendrolagi* is based primarily upon a single, well-preserved specimen from *D. bennettianus*, in which most, but not all features of its morphology can be observed. The type series is completed by a number of specimens from *D. lumholtzi*. The latter specimens are poorly preserved and while they are not differentiable from the holotype, are insufficient on their own to permit a full description. The description of the new species is therefore based on a collection of specimens from



Figs 6-10. *Progamotaenia irianensis* sp. nov. 6. Scolex. 7. Cirrus sac and genital atrium. 8. Premature segment showing patency of genital atria, filling of seminal receptacles with sperm but poor development of both male and female genitalia within segment. 9. Mature segment with fully developed genitalia and single uterus. 10. Pregravid segment with fully developed uteri. Drawings from types. Scale bars = 0.1 mm.

two host species within the same genus and may need to be reviewed if and when more extensive series of cestode specimens from these two host species become available. One feature of the new

species which warrants comment is the development of the genital atrium which becomes patent only in mature segments. This developmental feature has only been observed previously in *P. capricorniensis*

Beveridge & Turni, 2003 from the black-stripe wallaby, *Macropus dorsalis* (Gray, 1837), from central Queensland (Beveridge & Turni 2003), but provides an additional developmental character distinguishing the new species from all other congeners.

Progamotaenia irianensis sp. nov.
(FIGS 6-10)

Synonyms: *Progamotaenia* cf. *dorcopsis* of Flannery *et al.*, 1996, p. 187.

Holotype: From *Dendrolagus dorianus stellarum* Flannery & Seri, 1990, Gunung Ki, Tembagapura, Irian Jaya, Indonesia (4° 05' S, 137° 06' E), collected 19.v.1994 by T. Flannery, SAM AHC 28512.

Paratypes: 2 specimens, same data SAM AHC 28519-24; serial sections SAM AHC 28525 (5 slides), spirit material SAM AHC 32180.

Site in host: Small intestine.

Description

Large, robust cestodes, holotype 95 long, 6 wide, composed of 315 segments; paratype 67 long, width 5.0. Scolex prominently 4-lobed, 0.70–0.80 (0.75, $n = 3$) in diameter, with 4 oval suckers 0.36–0.44 (0.40, $n = 4$) long by 0.23–0.31 (0.26, $n = 4$) wide. Neck absent or very short. Segments transversely elongate, with prominent velum overhanging subsequent segment; posterior border of velum undulate with 29 (27–32, $n = 5$) blunt, linguiform projections overhanging succeeding segment on both dorsal and ventral aspects of strobila; as segments increase in size along strobila, velum covers $\frac{1}{2}$ to $\frac{2}{3}$ of succeeding segment. Premature segments 0.18–0.43 (0.28, $n = 5$) long, 3.86–4.17 (4.02, $n = 5$) wide, velum 0.16–0.29 (0.20, $n = 5$) long; mature segments 0.27–0.68 (0.45, $n = 5$) long, 4.25–5.15 (4.72, $n = 5$) wide, velum 0.23–0.44 (0.33, $n = 5$) long; pregravid segments 0.49–0.62 (0.56, $n = 5$) long, 4.91–5.85 (5.38, $n = 5$) wide, velum 0.29–0.55 (0.40, $n = 5$) long. Genital pores paired, in middle of lateral segment margins. In pre-mature segments, genital atrium circular in dorso-ventral views, not patent; in mature segments, genital atrium consists of narrow central passage with numerous anterior and posterior diverticula. Cirrus sac elongate, with thick muscular wall, extending just beyond osmoregulatory canals into medulla, 0.59–0.80 (0.69, $n = 5$) long, 0.15–0.17 (0.16, $n = 5$) wide in mature segments, 0.69–0.94 (0.81, $n = 5$) long, 0.19–0.25 (0.21, $n = 5$) wide in pregravid segments. Cirrus almost straight or with single flexure; armed

distally with numerous, regularly-arranged spines; distal segment of cirrus greatly dilated; width of cirrus diminishes proximally with similar reduction in size of spines; most proximal region of cirrus unarmed, leads into ellipsoidal or fusiform internal seminal vesicle 0.18–0.25 (0.23, $n = 5$) by 0.08–0.13 (0.10, $n = 5$) in mature segments, 0.34–0.44 (0.40, $n = 5$) by 0.15–0.17 (0.16, $n = 5$) in pregravid segments; cirrus sac between distal extremity and internal vesicle filled with densely-staining gland cells. External seminal vesicle clearly visible only in post-mature segments, elongate, extends medially and anteriorly from proximal pole of cirrus sac, along anterior border of seminal receptacle; covered with layer of glandular cells, 0.33–0.51 (0.41, $n = 5$) by 0.06–0.09 (0.08, $n = 5$); vas deferens arises from proximal pole of external seminal vesicle. Testes invariably arranged in two completely separate groups extending from ventral osmoregulatory canals to level of medial pole of seminal receptacle; 25–47 (37, $n = 5$) per group; 1 to 4 rows of testes in antero-posterior direction; 3–5 layers in dorso-ventral plane, 0.040–0.060 (0.050, $n = 10$) in diameter.

Vagina tubiform, opening to genital atrium posterior to cirrus sac; connection between vagina and genital atrium clearly visible in pre-mature segments prior to patency of genital atrium; once genital atrium becomes patent, distal vagina atrophies and becomes inapparent. Vagina leads to ovoid seminal receptacle on posterior margin of segment medial to cirrus sac and dorsal to female genitalia, 0.35–0.62 (0.48, $n = 5$) by 0.20–0.27 (0.24, $n = 5$); receptacle empty prior to patency of genital atrium, filled with sperm immediately genital atrium becomes patent. Ovary flabelliform, 0.24–0.33 (0.27, $n = 5$) by 0.47–0.78 (0.67, $n = 5$), ventral, with oöcap near medial pole of seminal receptacle; ovary on ventral aspect of medulla. Vitellarium horseshoe-shaped, posterior and dorsal to oöcap, 0.11–0.16 (0.12, $n = 5$) by 0.30–0.39 (0.34, $n = 5$). Mehlis' gland spherical, situated in U of vitellarium. Uterus usually paired in each segment, occasionally only a single uterus present; situated anterior to ovaries; immature uterus tubiform, extending laterally only to proximal poles of cirrus sacs; in pregravid segments, uterus develops numerous anterior and posterior diverticula, extends laterally dorsal to osmoregulatory canals, but does not cross canals. No gravid specimens present; eggs in all available specimens immature. Paired osmoregulatory canals present; ventral canal larger, 0.086–0.094 in diameter in mature segments, 0.094–0.24 in post-mature segments; dorsal canal external to ventral, much narrower, 0.016–0.031 in diameter in mature segments, 0.016–0.047 in diameter in post-mature segments; transverse canal connects ventral

canals at posterior margin of each segment; tiny accessory osmoregulatory canal observed medial to ventral canal in sections; transverse canal connects accessory canals at posterior margin of segment. Inner longitudinal musculature strongly developed, consisting of bundles of up to 20 muscle fibres concentrated in medial zone of cortex; transverse muscles form distinct band at cortico-medullary junction; dorso-ventral muscles prominent, arranged as numerous individual fibres crossing cortex and medulla.

Development of segments in holotype: genitalia fully formed by segment 100; genital atrium becomes patent in segment 120 and sperm appears in seminal receptacle in segment 123; uterus commences filling in segment 170; ovary involuted with remnants of vitellarium still present by segment 210; total number of segments 315.

Remarks

The species described above is based on few specimens which are fragmented and imperfectly preserved. However, because of the difficulty of obtaining material from tree kangaroos occurring at high altitudes in Irian Jaya, the description of a new species based on these specimens, albeit incomplete, is considered justified.

The species is characterised by two uteri, a prominently fimbriated velum and testes distributed exclusively in two groups. In a small number of segments, a single uterus is present, but the same phenomenon has been described previously in *P. festiva* by Beveridge (1976, p. 54) and is common in species of the anoplocephalid genus *Mosgovioya* Spasskii, 1951 from lagomorphs (Beveridge 1978a).

Species with a similar combination of characters are: *P. thylogale* Beveridge & Thompson, 1979, *P. lagorchestis* (Lewis, 1914), *P. spearei* Beveridge, 1980, *P. dorcopsis* Beveridge, 1985 and *P. queenslandensis* Beveridge, 1980. Of these species, *P. queenslandensis* frequently has the testes distributed in a single band as well as in two groups (Beveridge 1985). The species described above has an external seminal vesicle with a distinctive covering of glandular cells, thereby distinguishing it from *P. spearei*. The projections of the velum are distinctly linguiform in this species, differentiating them from the triangular projections seen in *P. lagorchestis*, *P. dorcopsis* and *P. queenslandensis*. The number of projections of the velum (27-32) also distinguishes the specimens from *P. thylogale* (18-21), *P. dorcopsis* (13-17) and *P. queenslandensis* (17-20) (Beveridge 1985). The number of testes per group (25-47) distinguishes the specimens from *P. thylogale* (50) and *P. dorcopsis* (18-25) (Beveridge 1985), while the distribution of the testes from the osmoregulatory canals to anterior to the aporal pole

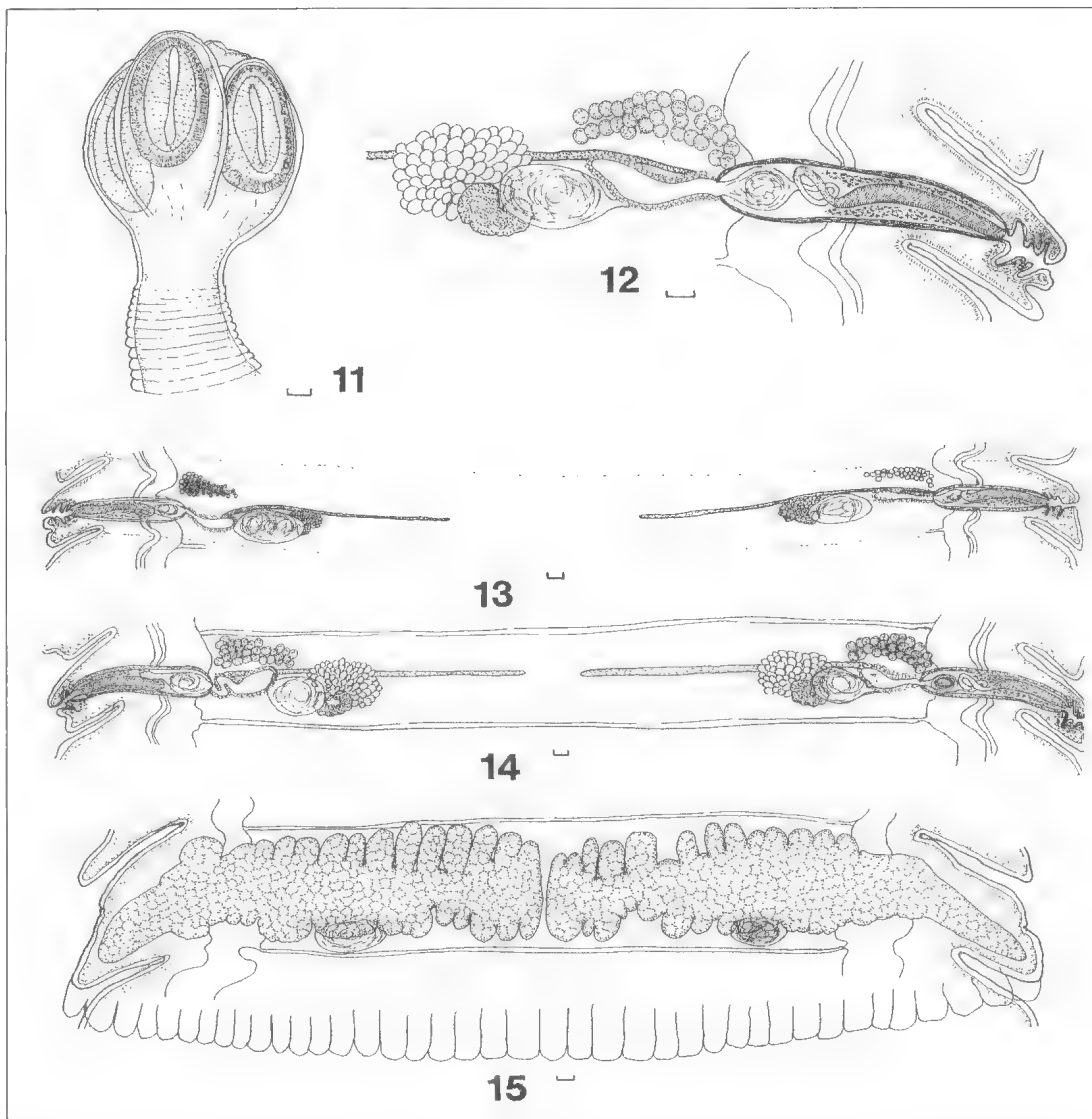
of the seminal receptacle distinguishes the species from *P. lagorchestis* in which the testes extend only to the poral pole of the seminal receptacle (Beveridge & Thompson 1979). The cestodes from *D. dorianus* have a similar number of linguiform projections to the velum as *P. capricorniensis*, but in the latter species a single uterus is present (Beveridge & Turni 2003). A singular feature of these specimens appears to be the fact that the uteri do not cross the osmoregulatory canals, even in near gravid segments. This character is unusual within the genus but has been reported in *P. zschokkei* (see Beveridge 1976, p. 67). In *P. spearei*, the uteri only cross the canals in the last few segments (Beveridge 1980). As fully gravid specimens were not available in the current series of specimens examined, it may be prudent not to rely on this feature as a specific character, but given the state of development of the specimens available, it seems unlikely that a major development of the uterus will occur beyond the 300th segment. Consequently, the species described above can be easily distinguished from all known congeners. It is therefore considered to be new and the specific name is given because these are the first new representative of the genus described from Irian Jaya, Indonesia.

Progamotaenia wallabiae Beveridge, 1985 (FIGS 11-15)

Material examined: 3 specimens from *Dendrolagus dorianus stellarum* Flannery & Seri, 1990, Gunung Ki, Tembagapura, Irian Jaya, Indonesia (4° 05' S, 137° 06' E), collected 19.v.1994 by T. Flannery, SAM AHC 28526-8; spirit material SAM AHC 32181.

Description

Large, robust cestodes, to 108 long, 5.0 wide, composed of 225 segments. Scolex prominently 4-lobed, 0.99 – 1.17 in diameter, with oval suckers, 0.62 – 0.70 (0.64, n = 4) by 0.35 – 0.47 (0.40, n = 4). Neck absent or very short, up to 0.23 long. Segments transversely elongate, with prominent velum overhanging subsequent segment; posterior border of velum very slightly undulate with c. 30-35 blunt-tipped lobes, not separated into individual projections, overhanging succeeding segment on both dorsal and ventral aspects of segment; as segments increase in size along strobila, velum covers $\frac{1}{2}$ to $\frac{2}{3}$ of succeeding segment. Premature segments 0.23 – 0.39 (0.29, n = 5) long by 3.82 – 4.91 (4.42, n = 5) wide, velum 0.09 – 0.18 (0.12, n = 5) long; mature segments 0.37 – 0.56 (0.44, n = 5) long by 4.52 – 6.40 (5.63, n = 5) wide, velum 0.21 – 0.27 (0.23, n = 5) long; pregravid segments 0.620 – 0.82 (0.73, n = 5) long by 4.29 – 5.30 (5.00, n = 5)



Figs 11-15. *Progamotaenia wallabiae* Beveridge, 1985. Specimens from *Dendrolagus dorianus*. 11. Scolex. 12. Genitalia of mature segment. 13. Premature segment following patency of genital atria and filling of seminal receptacles, but with male and female genitalia poorly developed. 14. Mature segment. 15. Pregravid segment. Scale bars = 0.1 mm.

wide, velum 0.35 – 0.64 (0.48, $n = 5$) long. Genital pores paired, in middle of lateral segment margins. In premature segments, genital atrium circular in dorso-ventral views, not patent; in mature segments, genital atrium consists of narrow central passage with numerous anterior and posterior diverticula. Cirrus sac elongate, with thick muscular wall, extending just beyond osmoregulatory canals into medulla; cirrus sac wider near proximal extremity; 0.70 – 0.86 (0.78, $n = 5$) long by 0.16 – 0.24 (0.20, $n = 5$) wide in mature segments, 0.92 – 1.09 (0.97, $n =$

5) long by 0.23 – 0.25 (0.24, $n = 5$) wide in pregravid segments. Distal cirrus greatly dilated, armed with numerous, regularly-arranged spines, 0.008 long; proximal cirrus narrow, coiled, with reduction in size of spines; most proximal region of cirrus unarmed, leads to fusiform internal seminal vesicle 0.22 – 0.36 (0.27, $n = 5$) long by 0.11 – 0.17 (0.14, $n = 5$) wide in mature segments, 0.24 – 0.47 (0.35, $n = 5$) long by 0.16 – 0.20 (0.18, $n = 5$) wide in pregravid segments; cirrus sac between distal extremity and internal vesicle filled with densely-staining gland cells.

External seminal vesicle elongate, 0.27 – 0.55 (0.43, $n = 5$) by 0.09 – 0.12 (0.10, $n = 5$), extends medially and anteriorly from proximal pole of cirrus sac, along anterior border of seminal receptacle; covered with layer of glandular cells; vas deferens arises from proximal pole of external seminal vesicle. Testes invariably arranged in two completely separate groups 30–57 (39, $n = 5$) per group, extending from ventral osmoregulatory canals to level of medial part of seminal receptacle; 1 to 4 rows of testes in antero-posterior direction; at least 2 layers in dorso-ventral plane; testis diameter 0.050 – 0.080 (0.060, $n = 10$). Vagina tubiform, opening to genital atrium posterior to cirrus sac; connection between vagina and genital atrium clearly visible in premature segments prior to patency of genital atrium; once genital atrium becomes patent, distal vagina atrophies and becomes inapparent. Vagina leads to ovoid seminal receptacle 0.32 – 0.44 (0.37, $n = 5$) by 0.19 – 0.28 (0.24, $n = 5$), on posterior margin of segment medial to cirrus sac; receptacle empty prior to patency of genital atrium, filled with sperm immediately genital atrium becomes patent. Ovary flabelliform, 0.24 – 0.43 (0.30, $n = 5$) by 0.43 – 0.57 (0.53, $n = 5$), with oöcapit near medial pole of seminal receptacle; ovary on ventral aspect of medulla. Vitellarium horseshoe-shaped, 0.14 – 0.20 (0.16, $n = 5$) by 0.23 – 0.27 (0.25, $n = 5$), posterior and dorsal to ovarian isthmus. Mehlis' gland spherical, 0.09 – 0.13 (0.11, $n = 5$) in diameter, situated in U of vitellarium. Uterus paired in each segment, situated anterior to ovaries; immature uterus tubiform, extending laterally to proximal poles of cirrus sacs; in pregravid segments, uterus develops numerous anterior and posterior diverticula, crosses osmoregulatory canals dorsally, extending to postero-lateral margins of segments. No gravid specimens present; eggs in all available specimens immature. Paired osmoregulatory canals present; ventral canal larger, 0.080 – 0.150 in diameter in mature segments, 0.140 – 0.310 in postmature segments; dorsal canal external to ventral, much narrower, 0.020 – 0.060 in diameter in mature segments, 0.040 – 0.050 in diameter in postmature segments; tiny accessory canals, 0.020 in diameter visible in some segments, medial to ventral canal; transverse canal connects ventral canals at posterior margin of each segment, diameter 0.020 – 0.060; tiny canal connecting dorsal canals 0.012 in diameter. Development of segments in largest specimen: genitalia formed but immature by segment 65; genital atrium becomes patent in segment 70; sperm appear in seminal receptacle in segment 73; first mature segment 95; uterus commences filling in segment 110; ovary involuted with remnants of vitellarium still present by segment 150; total number of segments 225.

Remarks

Progamotaenia wallabiae was described by Beveridge (1985) based on three specimens from the grey scrub wallaby, *Dorcopsis luctuosa* (D'Alberty, 1874) (= *D. veterum* (Lesson & Garnot, 1826) in Spratt *et al.* 1991) from Papua. Because the species was described from such a limited series of specimens and because its occurrence in the tree kangaroo, *D. dorianus*, involves a different host genus, a description of the specimens is provided. The occurrence of the species in *D. dorianus* was first reported by Flannery *et al.* (1996) and the description presented here is based on the specimens from the latter report.

The new specimens are not gravid, but do not differ significantly from the original specimens. The internal seminal vesicle is apparently larger than in the original description, but all other measurements conform closely with the description of *P. wallabiae*. Beveridge (1985) noted that the broad velum was undulate, with about 20 small lobes. In the new material, there are 30–35 distinct lobes on each side of the velum. Their arrangement is distinctive in that only the tips of the lobes are separated, while the divisions extend anteriorly into the velum without separation of the component lobes. This feature is unique within the genus as species have either a straight-edged velum or a velum split into prominent triangular or linguiform lobes. In the case of *P. thylogale*, the velum is scalloped, but there are no thickenings or divisions extending anteriorly beyond the edge. The feature described above may be characteristic of the species.

Discussion

The descriptions of cestodes of the genus *Progamotaenia* presented above suggests that tree kangaroos, while not harbouring a helminth fauna as diverse as some other macropodid genera, possess nevertheless distinctive species of cestodes. Descriptions are limited by the difficulty in obtaining material and by the fact that material obtained can rarely be preserved in an ideal manner. Nevertheless, it is possible to identify species and provide adequate descriptions of them from the material available. Notwithstanding the obvious limitations, some conclusions can be drawn on the species of *Progamotaenia* found in tree kangaroos.

Progamotaenia dendrolagi sp. nov. is found in both of the Australian species of tree kangaroos, *D. lumholtzi* and *D. bennettianus*, but has not, thus far been found in species in New Guinea. The Australian species of tree kangaroos are closely related phylogenetically (Flannery *et al.* 1996; Bowyer *et al.* 2003) and may either represent a recolonisation by the genus from New Guinea

(Winter 1997) or an endemic Australian phylogenetic lineage (Bowyer *et al.* 2003). The phylogenetic affinities of *P. dendrolagi* are not clear as the (intestinal) species which it most closely resembles, *P. ewersi*, is highly distinctive morphologically. In the absence of a formal phylogenetic analysis of the genus *Progamotaenia*, the affinities of *P. dendrolagi* are difficult to infer. It is apparently highly host specific as the species has not been found in other macropodids in north-eastern Queensland (Beveridge *et al.* 1989, 1992, 1998). Given the uncertainty as to the phylogenetic affinities of the cestode, its associations warrant further investigation and may provide significant insights into the mode of evolution of cestodes of macropodids.

Progamotaenia irianensis sp. n. was first reported as *P. cf. dorcopsis* (see Flannery *et al.* 1996) based on the presence of a prominently fimbriated velum, two uteri and the testes distributed in two distinct groups. The more detailed study presented here indicates that it is in fact a new species based on the number and shape of the elements of the velum. It has only been found in *D. dorianus* at a single locality in the mountains of Irian Jaya. The helminths of other macropodids occurring in the area are completely undocumented and therefore it is not possible to exclude the hypothesis that the species occurs commonly in other macropodids and may therefore not be primarily a parasite of tree kangaroos. The scrub wallabies which occur in the same general region, *Dorcopsis muelleri* (Schlegel, 1866) and *Dorcopsulus vanheurnei* (Thomas, 1922), should therefore also be considered as potential alternative hosts.

Progamotaenia wallabiae was first reported from *Dorcopsis luctuosa* from Papua (Beveridge 1985). The host reported in the original description was *D. veterum*, but this species was subsequently considered a *species inquirenda* by Groves & Flannery (1989). They indicated that the appropriate name for the scrub wallaby from the Port Moresby region was *D. luctuosa*. It may be that *P. wallabiae* is more widely distributed in species of *Dorcopsis*, than currently indicated by published records, and infects tree kangaroos which occur in sympatry with various species of scrub wallabies. However, the host and geographical distributions of the species are too poorly understood to allow conclusions to be drawn. The occurrence of *P. wallabiae* in tree kangaroos and scrub wallabies in New Guinea provides a striking contrast with *P. dendrolagi* in Australia which is apparently highly host specific and occurs only in tree kangaroos.

All species of anoplocephaline cestodes whose life cycles have been fully elucidated utilise oribatoid mites as intermediate hosts (Denegri 1993). No life cycles of species of *Progamotaenia* have been elucidated. However, in the case of species of the related cestode genus *Bertiella* Stiles & Hassall, 1902 occurring in Australian possums (*Trichosurus* spp.), also an arboreal mammal, the initial development of metacestodes has been observed in oribatid mites (Viggers & Spratt 1995) and therefore it seems likely that species of *Progamotaenia* may also utilise oribatoids as intermediate host. If this is the case, the life cycle is essentially terrestrial as the mites are common in soil and pastures (Denegri 1993). The most extensively studied species of *Dendrolagus* are the Australian species, *D. bennettianus* and *D. lumholtzi*. *D. lumholtzi* spends 99% of its time in the tree tops and together with *D. bennettianus*, subsists primarily on the leaves of rainforest trees and vines (Flannery *et al.* 1996). Consequently, the only opportunity for tree kangaroos to become infected with cestodes occurs when they feed on the ground and accidentally ingest mites which are infected with the intermediate stages (cysticercoids) of the parasites. This implies that they must feed on the ground in areas where faeces containing cestode eggs have fallen and consequently infected the local mite population. Given the biological features of the hosts, it is remarkable that they are infected by any anoplocephalid cestodes. Alternatively, the current studies of host biology may have underestimated the extent to which the kangaroos feed on the ground. Unpublished observations (PMJ) suggest that in contrast to the published data, both *D. bennettianus* and *D. lumholtzi* spend a substantial amount of time on the ground. Were they to feed consistently on the ground in areas in which species of *Dorcopsis* also occur, then a ready explanation could be provided for the occurrence of *P. wallabiae* in *D. dorianus*. More extensive studies both of the occurrence of parasites in tree kangaroos as well as of host biology are needed before the various questions posed by the present study can be resolved.

Acknowledgements

Our thanks are due to Tim Flannery and Dave Spratt for providing specimens for the current paper and to Dave Spratt for commenting on a draft of the manuscript. The work was supported financially by the Australian Biological Resources Study.

References

- BEVERIDGE I. (1976) A taxonomic revision of the Anoplocephalidae (Cestoda: Cyclophyllidae) of Australian marsupials. *Aust. J. Zool. Suppl. Ser.*, **44**, 1-110.
- (1978a) A taxonomic revision of the genera *Cittotaenia* Riehm, 1881, *Ctenotaenia* Railliet, 1893, *Mosgovoyia* Spasskii, 1951 and *Pseudocittotaenia* Tenora, 1976. *Mém. Mus. Nat. Hist. Nat., Sér. A, Zool.* **107**, 1-64.
- (1978b) *Progamotaenia ruficola* sp.n. (Cestoda: Anoplocephalidae) from the red kangaroo, *Macropus rufus* (Marsupialia). *J. Parasitol.* **64**, 273-276.
- (1980) *Progamotaenia* Nybelin (Cestoda: Anoplocephalidae) : new species, redescription and new host records. *Trans. R. Soc. S. Aust.* **104**, 67-79.
- (1985) Three new species of *Progamotaenia* (Cestoda: Anoplocephalidae) from Australasian marsupials. *Syst. Parasitol.* **7**, 91-102.
- (1994) Family Anoplocephalidae. Cholodkowsky, 1902. pp. 315-366 In Khalil, L.F., Jones, A., Bray, R.A. (Eds) "Keys to the Cestode Parasites of Vertebrates". (CAB International, Wallingford).
- , CHILTON N. B., JOHNSON P. M., SMALES L. R., SPEARE R. & SPRATT D. M. (1998) Helminth communities of kangaroos and wallabies (*Macropus* spp. and *Wallabia bicolor*) from north and central Queensland. *Aust. J. Zool.* **46**, 473-495.
- , SPEARE R., JOHNSON P. M. & SPRATT D. M. (1992) Helminth parasite communities of macropodoid marsupials of the genera *Hypsiprymnodon*, *Aepyprymnus*, *Thylogale*, *Onychogalea*, *Lagorchestes* and *Dendrolagus* from Queensland. *Wildl. Res.* **19**, 359-376.
- & SPRATT D. M. (1996) The helminth fauna of Australasian marsupials: origins and evolutionary biology. *Adv. Parasitol.* **37**, 136-254.
- , SPRATT D. M., CLOSE R. L., BARKER S. C. & SHARMAN G. B. (1989) Helminth parasites of rock-wallabies, *Petrogale* spp. (Marsupialia), from Queensland. *Aust. Wildl. Res.* **16**, 273-287.
- & THOMPSON R. C. A. (1979) The anoplocephalid cestode parasites of the spectacled hare-wallaby, *Lagorchestes conspicillatus* Gould, 1842 (Marsupialia: Macropodidae). *J. Helminthol.* **53**, 153-160.
- & TURNI C. (2003) *Progamotaenia capricorniensis* sp. nov. (Cestoda: Anoplocephalidae) from wallabies (Marsupialia: Macropodidae) from Queensland, Australia. *Parasite* **10**, 309-315.
- BOWYER, J. C., NEWELL, G. R., METCALFE, C. J. & ELDRIDGE, M. B. D. (2003) Tree-kangaroos *Dendrolagus* in Australia: are *D. lumholtzi* and *D. bennettianus* sister taxa? *Aust. Zool.* **32**, 207-213.
- DENEGRI, G. (1993) Review of oribatid mites as intermediate hosts of tapeworms of the Anoplocephalidae. *Exp. Appl. Acarol.* **17**, 567-580.
- FLANNERY, T.M., MARTIN, R. & SZALAY, A. (1996) Tree kangaroos : a curious natural history. (Reed Books : Melbourne).
- GROVES, C. P. & FLANNERY, T. F. (1989) Revision of the genus *Dorcopsis* (Macropodidae: Marsupialia) pp. 117-128. In Grigg, G., Jarman, P. & Hume, I. (Eds) "Kangaroos, wallabies and rat-kangaroos" (Surrey Beatty & Sons, Chipping Norton).
- LÖSER, E. (1965) Der Feinbau des Oogentop bei Cestoden. *Z. Parasitenkunde* **25**, 413-458.
- PRITCHARD, M. H. & KRUSE, G. O. W. (1982) The Collection and Preservation of Animal Parasites. (University of Nebraska Press, Lincoln).
- SPRATT, D. M., BEVERIDGE, I. & WALTER, E. L. (1991) A catalogue of Australasian monotremes and marsupials and their recorded helminth parasites. *Rec. S. Aust. Mus. Monogr. Ser.* **1**, 1-105.
- SCHMIDT, G. D. (1986) "CRC Handbook of Tapeworm Identification". (CRC Press, Boca Raton).
- TURNI, C. & SMALES, L. R. (1999) *Progamotaenia abietiformis* sp. nov. (Cestoda: Anoplocephalidae) from *Onychogalea fraenata* (Marsupialia: Macropodidae) from central Queensland. *Trans. R. Soc. S. Aust.* **123**, 143-147.
- WINTER, J. W. (1997) Response of non-volant mammals to Late Quaternary climatic changes in the Wet Tropics region of north-eastern Australia. *Wildl. Res.* **24**: 493-511.
- VIGGERS, K. L. & SPRATT, D. M. (1995) The parasites recorded from *Trichosurus* species (Marsupialia : Phalangeridae). *Ibid.* **22**, 311-332.

ANTENNAL SENSILLA OF SABATINCA STEROPS TURNER (LEPIDOPTERA: MICROPTERIGIDAE)

*By M. J. FAUCHEUX**

Summary

Faucheux, M. J. (2004). Antennal sensilla of *Sabatinca sterops* Turner (Lepidoptera: Micropterigidae) Trans. R. Soc. S. Aust. 128(2), 187-194, 30 November, 2004.

Male antenna sensilla of *Sabatinca sterops* were studied with a scanning electron microscope and compared with those already studied of another micropterigid moth, *Micropterix calthella*. The two species possess common sensilla types: multiporous sensilla (ascoids, trichodea, placodea, coeloconica), uniporous short sensilla basiconica, aporous sensilla (styloconica, chaetica, campaniformia, Böhm's bristles). They differ by the absence in *S. sterops* of multiporous sensilla basiconica, cupuliform organs and circular organs. The morphology of ascoid sensilla, s. styloconica and coeloconica is also different between the two species. Sensilla styloconica of *S. sterops* is typical of thermo-hygroreceptive sensilla styloconica of higher Lepidoptera. These results provide further evidence of the separation of the Micropterigidae into two groups: Micropterix-group and Sabatinca-group.

Key Words: Micropterigidae, *Sabatinca sterops*, *Micropterix calthella*, antenna, sensilla, ascoid, placodea, styloconica.

ANTENNAL SENSILLA OF *SABATINCA STEROPS* TURNER (LEPIDOPTERA: MICROPTERIGIDAE)

by M. J. FAUCHEUX*

Summary

FAUCHEUX, M. J. (2004) Antennal sensilla of *Sabatinca sterops* Turner (Lepidoptera: Micropterigidae). *Trans. R. Soc. S. Aust.* 128(2), 187-194, 30 November, 2004.

Male antenna sensilla of *Sabatinca sterops* were studied with a scanning electron microscope and compared with those already studied of another micropterigid moth, *Micropterix calthella*. The two species possess common sensilla types: multiporous sensilla (ascoids, trichodea, placodea, coeloconica), uniporous short sensilla basiconica, aporous sensilla (styloconica, chaetica, campaniformia, Böhm's bristles). They differ by the absence in *S. sterops* of multiporous sensilla basiconica, cupuliform organs and circular organs. The morphology of ascoid sensilla, s. styloconica and coeloconica is also different between the two species. Sensilla styloconica of *S. sterops* is typical of thermo-hygroreceptive sensilla styloconica of higher Lepidoptera. These results provide further evidence of the separation of the Micropterigidae into two groups: *Micropterix*-group and *Sabatinca*-group.

KEY WORDS: Micropterigidae, *Sabatinca sterops*, *Micropterix calthella*, antenna, sensilla, ascoid, placodea, styloconica.

Introduction

The Micropterigidae are considered as the most "primitive" lepidopteran family (Kristensen 1984, 1997). Whalley (1978) divided the Micropterigidae into two groups: the "Micropterigid-group" including the five genera *Micropterix*, *Epimartyria*, *Agrionympha*, *Paramartyria*, *Neomicropterix* and the "Sabatincoïd-group" including *Sabatinca*, *Agrionympha*, *Palaemicroides*, *Hypomartyria*, *Squamicornia*, and the fossil group *Parasabintaca* and *Undopterix*. According to Kristensen & Nielsen (1979), "there is a sister-group relationship between *Micropterix* and all other micropterigine genera; the two entities will be termed the *Micropterix*-group and the *Sabatinca*-group respectively". The recent distribution of the *Sabatinca*-group is wide. *Sabatinca* (about 23 species) occurs in Australia, New Zealand, and New Caledonia. *Agrionympha* occurs in South Africa, *Paramartyria* in Japan and Taiwan, *Palaemicroides* in Taiwan, *Neomicropterix* in Japan and *Epimartyria* in North America. The genus *Micropterix* (44 species) is almost exclusively confined to the Palaearctic region and is predominantly Western Palaearctic with the greatest species number in the mediterranean subregion (Kristensen & Nielsen 1979). Many characters are autapomorphies, either of the *Micropterix*-group, or the *Sabatinca*-group (Kristensen & Nielsen 1982).

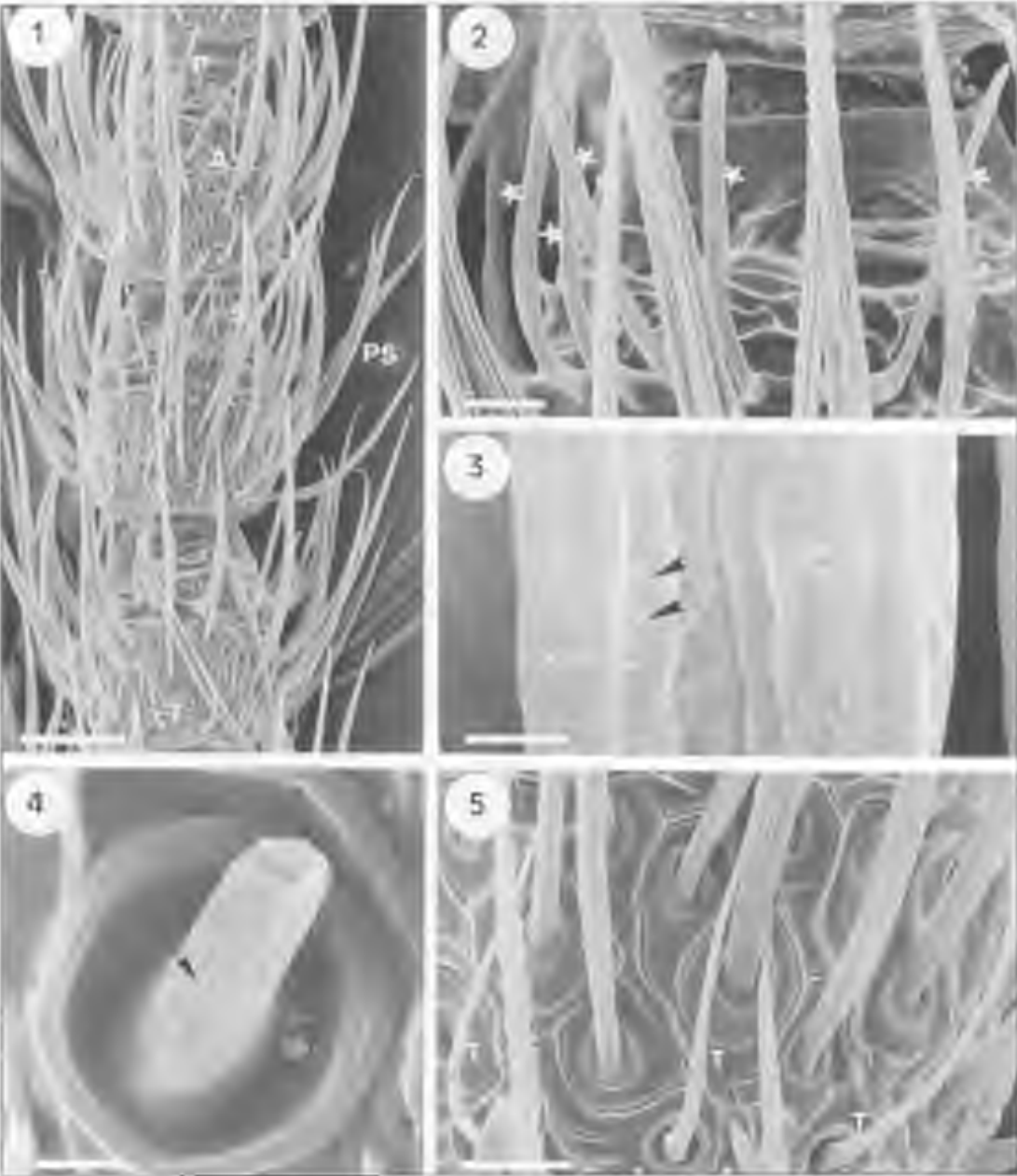
The aim of the present study is to discover the distinctive characteristics of the antennal sensory

organs of *Micropterix* and *Sabatinca* in order to justify the separation of Micropterigidae into these two groups. Antennal sensilla of Micropterigidae have only been considered in taxonomic reviews (Kristensen 1984) and in special studies devoted to the species *Micropterix calthella* L. (Le Cerf 1926, Fauchaux 1992 b, 1997). Concerning the *Sabatinca*-group, the only mentions of antennal sensilla are the following: ascoids, sensilla trichodea, sensilla coeloconica in *Hypomartyria micropteroides* Kristensen & Nielsen 1982; ascoids, sensilla coeloconica, absence of sensilla trichodea in *Squamicornia aequatoriella* Kristensen & Nielsen 1982 (Kristensen & Nielsen 1982). Nothing is known of the antennal sensilla of the genus *Sabatinca*.

Material and Methods

The moths *Sabatinca sterops* Turner 1921 were provided by the Australian National Insect Collection (A.N.I.C.), Division of Entomology, CSIRO, Canberra, Australia, thanks to the late Dr. E. B. Nielsen. They were collected at Moses Ck 4 km, Nby E. of Mt Finnigan, Queensland, 360 m, 14 oct. 1980, by E. D. Edwards. The antennae of males were dehydrated in an alcohol series to 100%, mounted on specimen holders and coated with a thin layer of gold and palladium in a J. F. C. 1100 sputter coater. Preparations were examined in a Jeol J. S. M. 6400 SEM at 7 kV. Counts of the sensilla were made on each flagellar segment in 8 males by using the SEM at different magnifications. The terminologies of Schneider (1964), Jefferson *et al.* (1970) and Zacharuk (1985) were used in naming the types of sensilla.

* Laboratoire d'Endocrinologie des Insectes Sociaux, Université de Nantes, 2 rue de la Houssinière, B.P. 92208, F-44322 Nantes Cedex 03, France.



Figs 1 - 5. Male adult of *Sabatinca sterops* – Scanning electron micrographs of antennal sensilla. Fig. 1. Three flagellomeres at mid length showing multiporous ascoid sensilla (A), multiporous sensilla trichodea (T), multiporous s. placodea (P), aporous s. styloconica (S) and piliform scales (PS). Scale bar = 20 μ m. Fig. 2. Multiporous ascoid sensillum with five branches (asterisks). Scale bar = 5 μ m. Fig. 3. Microsculpture of an multiporous ascoid sensillum whose pores are covered with a secretion (arrowheads). Scale bar = 0.5 μ m. Fig. 4. Break through a multiporous sensillum trichodeum with pores (arrow). Scale bar = 1 μ m. Fig. 5. Three multiporous sensilla trichodea (T). Scale bar = 5 μ m.

Results

The antennae in male *Sabatinca sterops* are long, 0.7 – 0.8 length of forewing coata. The scape and pedicel are swollen, markedly wider than basal flagellomeres. The ratios for the scape, the pedicel and the first flagellomere are the following : width = 2.7, 2.2, 1 ; length = 3, 2, 1. The flagellum consists of 36 flagellomeres. The basal flagellomeres are almost cylindrical, the segments 5 onwards are distinctly moniliform and longer than they are wide, and increasingly so towards the antennal apex. The scape and the pedicel are covered with lamellar scales and additionally with ventral tufts of long piliform scales. On each flagellomere, the sockets of piliform scales are arranged in 3-5 annuli in the proximal, swollen part of the segment.

Seven types of sensilla exist all around the flagellar segments: multiporous ascoid sensilla, multiporous s. trichodea, multiporous s. placodea, aporous s. styloconica, uniporous s. basiconica, aporous s. chaetica and multiporous s. coeloconica, while the scape and the pedicel are provided with aporous s. campaniformia and Böhm's bristles.

None of these antennal structures is glandular and thus, they are sensilla in the strict sense.

Multiporous ascoid sensilla are large and multibranched sensilla which consist of thin-walled

hairs arising from a linear and medial cuticular depression (Figs 1, 2, Table 1). The long axis of the hairs is arranged parallel to the longitudinal axis of the antenna as in the sensillum vesiculocladum of Nepticulidae (Nieukerken & Dop 1987) but, unlike those of this sensillum, the hairs are not fused with the antennal cuticle throughout their length. Lined pores are only located on the outer face of branches (Fig. 3). The number of branches, smaller in the basal flagellomeres, rises to a maximum of 8 from the 7th segment onwards. Except the first and the apical ones, all flagellomeres possess two ascoid sensilla opposite each other (Table 2).

Multiporous sensilla trichodea are long and slender hairs, curved at the base, with the whole of the surface wall perforated with lined pores (Fig 4, 5, Table 1). These sensilla occur on all the flagellomeres, preferentially on the proximal edge (Fig. 5) ; their numbers vary from 1 to 18 per segment (Table 2). They are more numerous on the distal part of the flagellum than on the proximal one.

Multiporous sensilla placodea are plate organs, 5 µm in diameter (Table 1), with the upper surface perforated with pores (Fig. 7). They are located ventrally at the distal edge of the flagellomere between the two ascoid sensilla (Figs 1, 6). This sensillar type never exceeds one sensillum per segment, except on the first and apical segment (Table 2).

Aporous sensilla styloconica are stout pegs with an inflexible stylus 16 µm long, and a non-porous cone 2 µm long (Figs 1, 8, Table 1). They are typically located at the distal edge of flagellomeres. Except for the proximal and apical flagellomeres, there is only one sensillum per segment (Table 2).

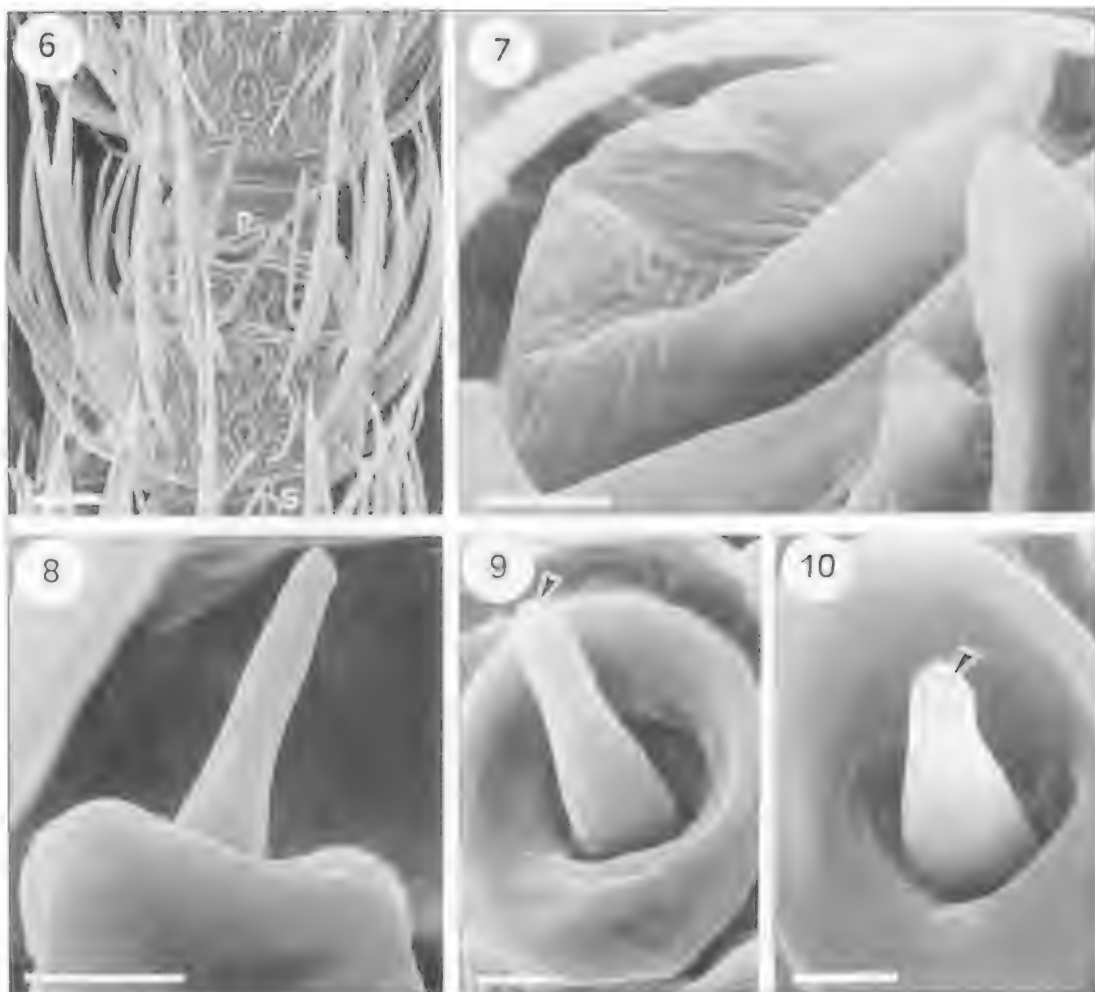
Uniporous short sensilla basiconica are short sensilla which may be confused with sensilla coeloconica. They differ by the presence of a basal cupola and a smooth cone perforated with only a terminal pore. Their shape and length vary slightly from one segment to another (Figs 8, 9). Sometimes absent, they do not exceed one sensillum per segment (Table 2).

TABLE 1. Mean length and basal width of the sensilla of antennae of *Sabatinca sterops* (n = 20 for each type of sensillum). * width of one branch.

Sensilla	Length (µm) (mean +/- S.D.)	Basal width (µm) (mean +/- S.D.)
Ascoid sensilla	27.2 +/- 0.87	2.3 +/- 0.12*
S. trichodea	19.5 +/- 0.34	1.1 +/- 0.02
S. styloconica	17.9 +/- 0.21	2.1 +/- 0.07
S. basiconica	3.6 +/- 0.25	1.3 +/- 0.04
S. coeloconica	3.2 +/- 0.13	0.9 +/- 0.02
S. chaetica	25.7 +/- 0.28	1.4 +/- 0.09
Böhm's bristles	6.7 +/- 0.19	0.9 +/- 0.05
S. placodea	-	5.3 +/- 0.08
S. campaniformia	-	7.4 +/- 0.14

TABLE 2. Number of sensillar types on male *Sabatinca sterops* antennal flagellum on different segments (based on 8 antennae (mean +/- S.D.).

Flagellar segment n°	Ascoid sensilla	Sensilla trichodea	Sensilla styloconica	Sensilla basiconica	Sensilla coeloconica	Sensilla chaetica	Sensilla placodea
1	0	1 +/- 0.2	0	0	0	0	0
5	2 +/- 0.1	4 +/- 1.2	1 +/- 0.0	1 +/- 0.4	1 +/- 0.2	3 +/- 0.1	1 +/- 0.0
15	2 +/- 0.0	9 +/- 1.8	1 +/- 0.0	1 +/- 0.2	1 +/- 0.1	0	1 +/- 0.0
25	2 +/- 0.0	11 +/- 2.4	1 +/- 0.0	1 +/- 0.5	1 +/- 0.3	2 +/- 0.1	1 +/- 0.2
30	2 +/- 0.0	16 +/- 2.2	1 +/- 0.0	0	1 +/- 0.1	5 +/- 0.5	1 +/- 0.1
Anteapical	2 +/- 0.1	18 +/- 2.7	0	1 +/- 0.3	0	4 +/- 0.7	1 +/- 0.0
Apical	0	10 +/- 1.5	0	1 +/- 0.2	0	12 +/- 1.4	0
Estimated total per antenna	68	347	32	25	31	94	33



Figs 6 – 10. Male adult of *Sabatinca sterops* – Scanning electron micrographs of antennal sensilla. Fig. 6. Location of the multiporous sensillum placodeum (P) and the aporous sensillum styloconicum (S) on a flagellomere. Scale bar = 10 μ m. Fig. 7. Sensillum placodeum. Scale bar = 1 μ m. Fig. 8. Apex of an aporous sensillum styloconicum. Scale bar = 1 μ m. Fig. 9. Uniporous short sensillum basiconicum showing the terminal pore (arrow). Scale bar = 1 μ m. Fig. 10. Another uniporous short sensillum basiconicum. Scale bar = 1 μ m.

Aporous sensilla chaetica are longer than sensilla trichodea (Table 1). The non-porous hair is sculptured with longitudinal ridges and scutes (Fig. 11). These sensilla differ from piliform scales by their shorter length and the existence of a bulbous, raised base which closely surrounds the hair. Few in number, they constitute two rings on the apical segment (Table 2).

A single multiporous sensillum coeloconicum, without a fence of microtrichia, is present at the same level as the ascoids and between them. The peg possesses longitudinal grooves with pores located between two adjacent grooves (Fig. 12). Their number is identical to that of the sensilla styloconica (Table 2).

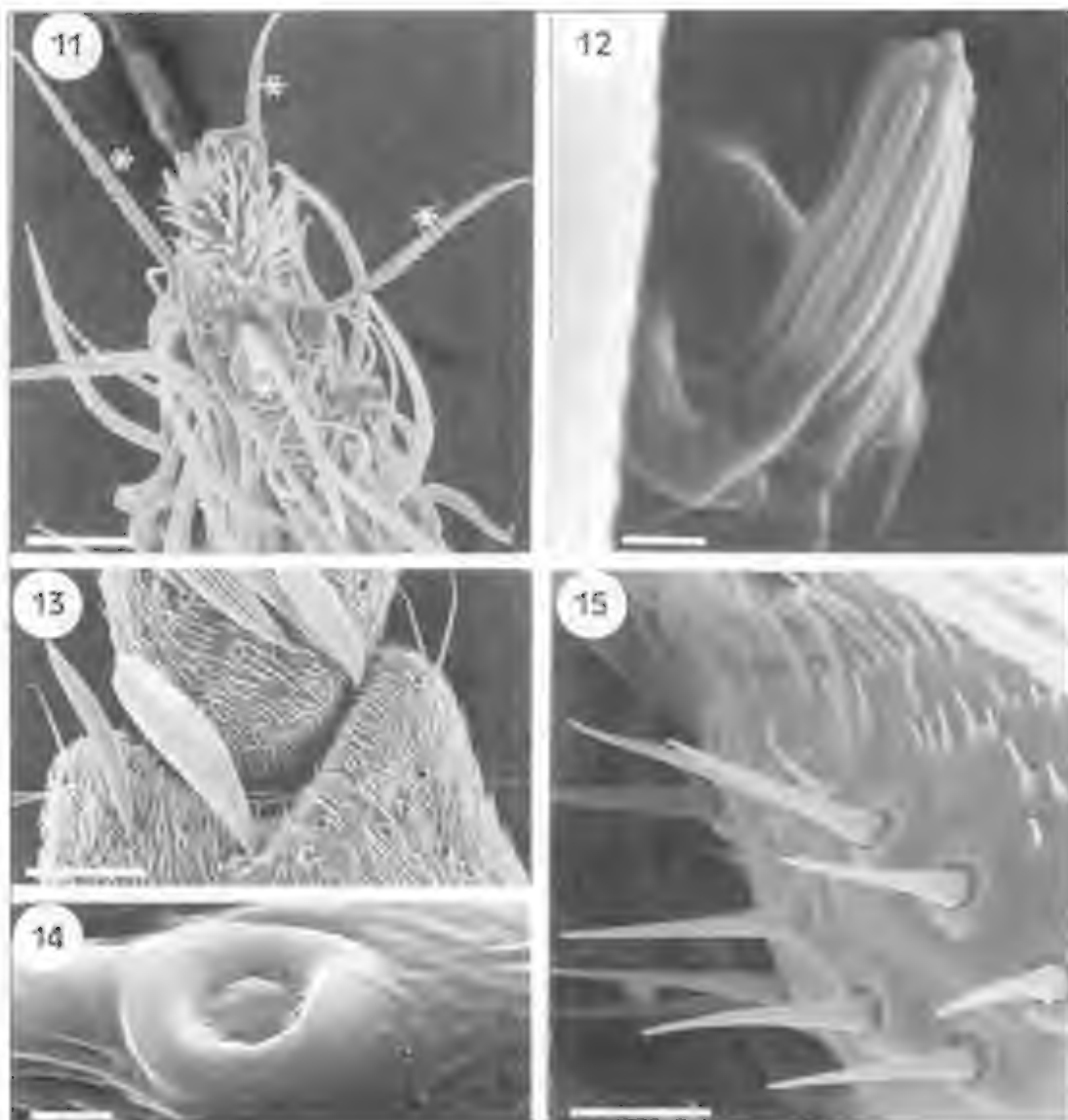
One aporous sensillum campaniformium is located at the apex of pedicel (Fig. 13). Its central dome, 2 μ m in diameter, is surrounded by an alveola 7.4 μ m in diameter.

Aporous Böhm's bristles 7 μ m long, with a smooth wall surface, are situated in three groups at the base of the scape and two groups at the base of the pedicel (Fig. 15), each group possessing about 10 sensilla.

Discussion

1 – Common characteristics

Micropterix calthella and *S. sterops* possess common antennal sensilla: ascoid sensilla, s.



Figs 11–15. Male adult of *Sabatinca sterops*. Scanning electron micrographs of antennal sensilla. Fig. 11. Aporous sensilla chaetica (asterisks) on the apical flagellomere. Scale bar = 10 μm . Fig. 12. Naked multiporous sensillum coeloconicum. Scale bar = 0.5 μm . Fig. 13. Aporous sensillum campaniformium on the apex of the pedicel (C). Scale bar = 20 μm . Fig. 14. Sensillum campaniformium. Scale bar = 2 μm . Fig. 15. Aporous Böhm's bristles at the base of the pedicel. Scale bar = 4 μm .

placodea, s. trichodea, short s. basiconica, s. coeloconica, s. chaetica, s. styloconica, s. campaniformia and Böhm's bristles.

Ascoïd sensilla are currently considered to be a good autapomorphy of the Micropterigidae (Kristensen & Nielsen 1979). They were described as "organes de Tonnoir" from the antenna in *Micropterix* by Le Cerf (1926). They are present in

all other genera of Micropterigidae. Indeed, these sensilla are also observed in *Squamicornia aequatoriella* Kristensen & Nielsen, 1982 and *Hypomartyria micropteroides* Kristensen & Nielsen, 1982 (Kristensen & Nielsen 1982). However, ascoïd sensilla are also described from other families of Lepidoptera as Nepticulidae (Nieukerken & Dop 1987) and Opostegidae (Davis 1975). Nevertheless,

if the gross morphology of these sensilla resembles that of the Micropterigidae, there are important differences between the three families (Faucheux 1999). The piliform branches of ascoids in *Micropterix* are separated from the antennal integument whereas, in Nepticulidae, the branches of sensilla vesiculoclada are fused with the antennal cuticle throughout their length. Moreover, the branches in Opostegidae are true hairs whose pores are scattered all over the circumference of the hair whereas only the upper surface of the flattened branches is porous in *Micropterix* and *Sabatinca*.

Sensilla placodea of Micropterigidae are described for the first time in *M. calthella* by Faucheux (1992). Their surface is provided with pores seen both in scanning electron microscopy (Faucheux 1992) and in transmission electron microscopy (Hallberg & Hansson 1999). The present study shows that these sensilla also exist in *S. sterops*. To date, they have not been found to in all other families of lower and higher Lepidoptera. Indeed, contrary to the opinion of Hallberg & Hansson (1999), the Eriocraniidae do not possess this type of sensilla; the authors confuse the sensilla auricillica present in the eriocraniid moths with the sensilla placodea. If the presence of sensilla placodea was confirmed in other genera of Micropterigidae, these sensilla, rather than the ascoid sensilla, could be considered autapomorphic of the ground plan of the Micropterigidae (Faucheux 2004).

The absence of sensilla auricillica which is interpreted as an autapomorphy of the family Micropterigidae by Kristensen & Nielsen (1979) is confirmed in *Sabatinca*. According to them, the presence of these sensilla may reasonably be attributed to the lepidopteran ground plan since, besides existing in Heterobathmiidae, they have been reported in Eriocraniidae, Acanthopteroctetidae, Nepticulidae (Davis 1978), Hepialidae (Flower & Helson 1976), Tortricidae (Wall 1978), Noctuidae (Faucheux 1990b), Sphingidae (Shields & Hildebrand 1999) and Pyralidae (Faucheux 1992a; Castrejón Gómez *et al.* 2003). We have checked their presence in Rhopalocera (Faucheux 1996).

Uniporous short sensilla basiconica are also described in *M. calthella* where they exist in two forms as in *S. sterops*. Such sensilla have only been described in the Aglossata *Agathiphaga* sp. (Faucheux 1990 a).

2 – Different characteristics

The ascoid sensilla of *Micropterix* consist of radial branches that share a common circular base (Faucheux 1992 b). In *S. sterops*, the branches are mainly arranged parallel to the longitudinal axis of the antenna. Thus, the sensilla of *S. sterops* resemble more closely the sensilla vesiculoclada of

Nepticulidae than the sensilla of *Micropterix*. The micropterigids of the *Sabatinca*-group lack the "radial" ascoid sensilla so typical of all other members of the family (G. W. Gibbs, pers. com.).

The sensilla styloconica of *M. calthella* differ from typical sensilla of Lepidoptera by having a long hair of 30 µm instead of a cone (Faucheux 1997). In Lepidoptera, styloconic sensilla with a long hair have only been described on the antennae of two neopseustid moths, *Neopseustis archiphenax* Meyrick (Davis 1975) and *Apoplania valdiviana* Davis & Nielsen 1984 (Faucheux 1999). Thus, the sensillum styloconicum with a short and smooth cone of *S. sterops* resembles those of higher Lepidoptera. Moreover, the hair of sensilla styloconica in *M. calthella* possesses longitudinal ridges and spines and is therefore identical to the sensilla chaetica present in that species and in *S. sterops*. In some antennal segments of *Micropterix*, the stylus is reduced to a short base and thus the sensillum styloconicum resembles a typical sensillum chaeticum. Only its position at the distal edge of segment 1, between the two ascoid sensilla, makes possible its identification. Our knowledge of the physiology of the antennal styloconic sensilla of insects and of Lepidoptera in particular (Altner *et al.* 1983; Steinbrecht 1998), makes it difficult to assign a thermo-hygroreceptive function to the sensilla of *M. calthella*. On the contrary, the short, smooth and aporous sensory cone of *S. sterops* possesses an identical morphology to that of the styloconic sensilla of the majority of Lepidoptera. Indeed, according to Altner *et al.* (1983), the presence of a peg, the lack of pores, the lack of socket structures which would indicate flexibility, and the presence of three types of sensory cells, are common features of thermo- and hygroreceptors. Detailed ultrastructural and electrophysiological research would be necessary to confirm the existence of the three cellular types in the two micropterigid moths.

All the sensilla coeloconica of *S. sterops* are naked whereas in *M. calthella*, the majority are surrounded by a circular fence of microtrichia and only certain sensilla are deprived of microtrichia. No conclusion can be drawn from this difference because the three cases (coeloconica with a fence of microtrichia; naked coeloconica; coeloconica with and without a fence of microtrichia) exist in various families of lower and higher Lepidoptera (Faucheux 1999).

Of the 12 types of sensilla described in *M. calthella*, *S. sterops* possesses only 9. This latter species is without multiporous sensilla basiconica, cupuliform organs and circular organs. The absence of the multiporous sensilla basiconica is surprising because these sensilla are part of the basal antennal sensory equipment of Lepidoptera (Faucheux 1999).

As the antennae of the females have not been studied, it is possible that they possess this type of sensilla. Another explanation may be the small number of these sensilla in the male of *M. calthella*, equivalent to 2% of the sensilla trichodea with which the multiporous sensilla basiconica may be confused.

Cupuliform organs do not form part of the ubiquitous sensilla of the antennae. They have been described in only three species belonging to remote families from a systematic point of view: *M. calthella* (Faucheux 1997), *A. valdiviana* (Faucheux 1999) and the pyralid *Homoeosoma nebulella* Den. & Schiff. (Faucheux 1992 a). If the thermo- and hygroreceptive function is not performed by the sensilla styloconica in *M. calthella*, it could be by the cupuliform organs which are classed among the sensilla ampullacea (Faucheux 1999). Indeed, the sensilla ampullacea on the antennae of mosquitoes possess thermo- and hygroreceptors (Boo & McIver 1975 ; Steinbrecht 1998). The small number of these sensilla and the absence of sexual dimorphism in *Micropterix* are characteristic of these types of receptors. Following this hypothesis, the absence of cupuliform organs in *S. sterops* may be justified by

the presence of typical sensilla styloconica adapted to thermo- and hygroreception.

The greatest contribution of the antennal study of *S. sterops* is to define a distinctive "Australian" species-group. This micropterigid lacks the radial ascoid sensilla which are so typical of all other members of the family such as *M. calthella* (*Micropterix*-group) but also of the *Sabatınca*-group such as the two South American species: *Hypomartyria micropteroides* and *Squamicornia aequatoriella* (Kristensen & Nielsen 1982). Further observations of the different species of the two groups of Micropterigidae will be necessary to confirm the above results.

Acknowledgments

We wish to acknowledge the courtesy of the late Dr. E. B. Nielsen for providing the specimens of *Sabatınca sterops*. It is a pleasure to acknowledge the technical assistance of M. Alain Barreau (Centre of Scanning Electron Microscopy, University of Nantes, France), Mrs Odile Aumaille, and Mr V. Ballardini for help with the translation.

References

- ALTNER, H., SCHALLER-SELZER, L., STEITZ, H. & WOHLEB, I. (1983) Poreless sensilla with inflexible sockets: a comparative study of a fundamental type of insect sensilla probably comprising thermo- and hygroreceptors. *Cell Tissue Res.* **234**, 279-307.
- BOO, K. S. & MCLIVER, S. B. (1975) Fine structure of sunken thick-walled pegs (sensilla ampullacea and coeloconica) on the antennae of mosquitoes. *Can. J. Zool.* **53**, 262-266.
- CASTREJÓN GÓMEZ, V. R., NIETO, G., VALDES, J., CASTREJÓN, F. & ROJAS, J. C. (2003) The antennal sensilla of *Zamagiria dixolophella* Dyar (Lepidoptera : Pyralidae). *Ann. Ent. Soc. Amer.* **96**, 672-678.
- DAVIS, D. R. (1975) Systematics and zoogeography of the family Neopseustidae with the proposal of a new superfamily (Lepidoptera: Neopseustoidea). *Smith. Contr. Zool.* **210**, 1-45.
- (1978) A revision of the North American moths of the superfamily Eriocranioidea with the proposal of a new family, Acanthopterocetidae (Lepidoptera). *Ibid.* **251**, 1-131.
- FAUCHEUX, M. J. (1990 a) Antennal sensilla in adult *Agathiphaea vittensis* Duml. and *A. queenslandensis* Duml. (Lepidoptera: Agathiphaeidae). *Int. J. Insect Morphol. & Embryol.* **19**, 257-268.
- (1990 b) External ultrastructure of sensilla on the male and female antennal flagellum of *Noctua pronuba* L. (Lepidoptera: Noctuidae). *Ann. Soc. Ent. Fr. (N. S.)* **26**, 173-184.
- (1992 a) Organes cupuliformes et dimorphisme sexuel de l'antenne de la Pyrale européenne du tournesol, *Homoeosoma nebulella* Den. & Schiff. (Lepidoptera: Pyralidae). *Bull. Soc. Sci. Nat. Ouest Fr. (N. S.)* **14**, 44-52.
- (1992 b) Structures sensorielles et glandulaires particulières de l'antenne de *Micropterix calthella* L. (Lepidoptera: Micropterigidae). *Ibid.* **14**, 114-118.
- (1996) Sensilles auriculiformes sur l'antenne des Rhopalocères. Étude de la Piéride de la rave, *Pieris rapae* L. (Lepidoptera: Pieridae). *Ibid.* **18**, 93-97.
- (1997) Sensory organs on the antennae of *Micropterix calthella* L. (Lepidoptera: Micropterigidae). *Acta Zoologica* (Stockholm) **78**, 1-8.
- (1999) "Biodiversity and unity of sensory organs in Lepidopteran Insects". *Suppl. H. S. Bull. Soc. Sci. Nat. Ouest Fr. (N. S.)*, 296 pp. [In French, fully English summaries of all chapters, figure legends translated].
- (2004) Sensilla placodea on the antennae of Lepidoptera. *Annls. Soc. Ent. Fr. (N. S.)* **40**, 105-107.
- FLOWER, N. E. & HFLSON, G. A. H. (1976) Variation in antennal sensilla of some hepialid moths; a scanning electron microscope study. *N. Z. J. Zool.* **3**, 327-331.
- HALLBERG, E. & HANSSON, B. S. (1999) Arthropod sensilla: morphology and phylogenetic considerations. *Microsc. Res. Tech.* **47**, 428-439.
- JEFFERSON, R. N., RUBIN, R. E., MCFARLAND, S. U. & SHOREY, H. H. (1970) Sex pheromones of noctuid moths. XXII. The external morphology of the antennae of *Trichoplusia ni*, *Heliothis zea*, *Prodenia ornithogalli* and *Spodoptera exigua*. *Ann. Ent. Soc. Amer.* **63**, 1227-1238.
- KRISTENSEN, N. P. (1984) Studies on the morphology and systematics of primitive Lepidoptera (Insecta). *Steenstrupia* **10**, 141-191.
- & NIELSEN, E. B. (1979) A new subfamily of micropterigid moths from South America. A contribution to the morphology and phylogeny of the Micropterigidae, with a generic catalogue of the family (Lepidoptera: Zeugloptera). *Ibid.* **5**, 69-147.

- _____ & _____ (1982) South American micropterigid moths: two new genera of the *Sabatinca*-group (Lepidoptera: Micropterigidae). *Ent. scand.* **13**, 513-529.
- LE CERF, F. (1926) Contribution à l'étude des organes sensoriels des Lépidoptères. *Encycl. Ent. B III* (Lepidoptera) **1**, 131-158.
- NIEUKERKEN, E. J. VAN & DOP, H. (1987) Antennal sensory structures in Nepticulidae (Lepidoptera) and their phylogenetic implications. *Z. zool. syst. Evolut.-forsch.* **25**, 104-126.
- SCHNEIDER, D. (1964) Insect antennae. *Annu. Rev. Ent.* **9**, 103-122.
- SHIELDS, V. D. C. & HILDERBRAND, J. G. (1999) Fine structure of antennal sensilla of the female sphinx moth, *Manduca sexta* (Lepidoptera: Sphingidae). II. Auriculate, coeloconic, and styloform complex sensilla. *Can. J. Zool.* **77**, 302-313.
- STEINBRECHT, R. A. (1998) Bimodal thermo- and hygrosensitive sensilla pp. 405-422 In Harrison F. W. and Locke M. (Eds.) "Microscopic Anatomy of Invertebrates", vol. 11 B: Insecta (Wiley-Liss, New York).
- WALL, C. (1978) Morphology and histology of the antennae of *Cydia nigricana* (F.) (Lepidoptera: Tortricidae). *Int. J. Insect Morphol. & Embryol.* **7**, 237-250.
- WHALLEY, P. E. S. (1978) New taxa of fossil and recent Micropterigidae with a discussion of their evolution and a comment on the evolution of the Lepidoptera (Insecta). *Ann. Trans. Mus.* **31**, 71-86.
- ZACHARUK, R. Y. (1985) Antennae and sensilla pp. 1-70 In Kerkut G. A. & Gilbert L. I. (Eds.) "Comprehensive Insect Physiology, Biochemistry and Pharmacology", vol. 6 (Pergamon Press, London).

TWELVE NEW SPECIES OF AUSTRALIAN BUPRESTIDAE (COLEOPTERA) AND NEW SYNONYMY

*BY S. BARKER**

Summary

Barker, S. (2004) Twelve new species of Australian Buprestidae (Coleoptera) and new synonymy. Trans. R. Soc. S. Aust. 128(2)195-204, 30 November, 2004.

Eleven new species of Castiarina are described namely: *C. bilyi*, *C. bugejana*, *C. coalstounensis*, *C. chlorota*, *C. darkinensis*, *C. denmanensis*, *C. gilberti*, *C. kitchini*, *C. markgoldingi*, *C. moxoni*, *C. pallida* and one new species of *Astraeus* namely *A. kitchini*. *Castiarina suttoni* (Carter, 1932) is resurrected from synonymy with *Castiarina deuqueti* (Carter, 1927)

Key Words: Coleoptera, Buprestidae, New species, Castiarina, Astraeus.

TWELVE NEW SPECIES OF AUSTRALIAN BUPRESTIDAE (COLEOPTERA) AND NEW SYNONYMY

by S. BARKER*

Summary

BARKER, S. (2004) Twelve new species of Australian Buprestidae (Coleoptera) and new synonymy. *Trans. R. Soc. S. Aust.* **128**(2), 195-204, 30 November, 2004.

Eleven new species of *Castiarina* are described namely: *C. bilyi*, *C. bugejiana*, *C. coalstounensis*, *C. chlorota*, *C. darkinensis*, *C. denmanensis*, *C. gilberti*, *C. kitchini*, *C. markgoldingi*, *C. moxoni*, *C. pallida* and one new species of *Astraeus* namely *A. kitchini*. *Castiarina suttoni* (Carter, 1932) is resurrected from synonymy with *Castiarina deuqueti* (Carter, 1927).

KEY WORDS: Coleoptera, Buprestidae, New species, *Castiarina*, *Astraeus*.

Materials and Methods

Specimens examined were borrowed from or are deposited in the following institutions and collections:

- AMSA - Australian Museum, Sydney.
- ANIC - Australian National Insect Collection, Canberra.
- ASSH - A. Sundholm, Sydney.
- DKQA - D. Kitchin, Toowoomba.
- MHSA - M. Hanlon, Sydney.
- MPWA - M. Powell, Melville and M. Golding, Beverley.
- PMCE - Prague Museum, Czechoslovakia.
- QMBA - Queensland Museum, Brisbane.
- SAMA - South Australian Museum, Adelaide.
- WAMA - Western Australian Museum, Perth.

Male genitalia were prepared and illustrated by the method described in Barker (1987). Habitus illustrations were prepared by photographing each holotype, projecting the image onto copy paper at 6 times natural size, then drawing around the image in pencil. The paper was folded along the mid-line of the image, placed over a light box and the sides equalised. The resultant outline was traced onto pencil board and the details drawn in with pencil. Smudge sticks and a plastic eraser were used for fine shading. The completed drawings were sealed with mat fixative. Finally they were scanned into a computer and the images manipulated using Photoshop. Measurements given are total body length and width of the holotype, followed by the range of these measurements for all males and females. Codens used in the text for museum and private collections follow the four letter system of Watt (1979) and Arnett *et al.* (1993).

Introduction

Largely because of the enthusiasm of a number of collectors, the Australian buprestids are now much better known than they were twenty five years ago. For the last thirty four years I have been working towards a revision of *Castiarina* (Gory & LaPorte), the species of which are some of the most difficult to identify. Again, before that task is completed more species have been brought to my attention and these are described below, together with a new species of *Astraeus* (Gory & LaPorte) (s.s.). *A. blackdownensis* Barker, 1977 was described from a unique female specimen. A series of both sexes was collected at Blackdown Tableland, Queensland on 25.x.2001 on *Allocasuarina inophloia* (F. Muell. & F. M. Bailey) L. A. S. Johnson by myself and M. Powell. Specimens have been deposited in the QMBA and SAMA collections.

Resurrection of a *Castiarina* species

In an earlier paper on the genus *Castiarina* (Barker 1980) I synonymised *Castiarina suttoni* (Carter, 1932) and *Castiarina palagera* (Carter, 1937) with *Castiarina deuqueti* (Carter, 1927). Recently I have re-examined all of the holotypes: ♂ holotype, *C. deuqueti*, Armidale, NSW, C. Deuquet, AMSA K58167; ♀ holotype, *C. suttoni*, E. Sutton, Fletcher, Queensland, AMSA K67341; ♂ holotype, *C. palagera*, Cessnock, NSW, W. Duboulay, AMSA K104458. On the basis of the structure of male genitalia and external morphology I conclude that *C. palagera* is a synonym of *C. suttoni* which is a separate species from *C. deuqueti*.

Castiarina bilyi sp. nov.
(Figs 1i, 2b)

Holotype

♂, Hyden, W.A., 25.x.2001, S. Bílý, WAMA.

* Department of Entomology, South Australian Museum Adelaide, South Australia 5000.

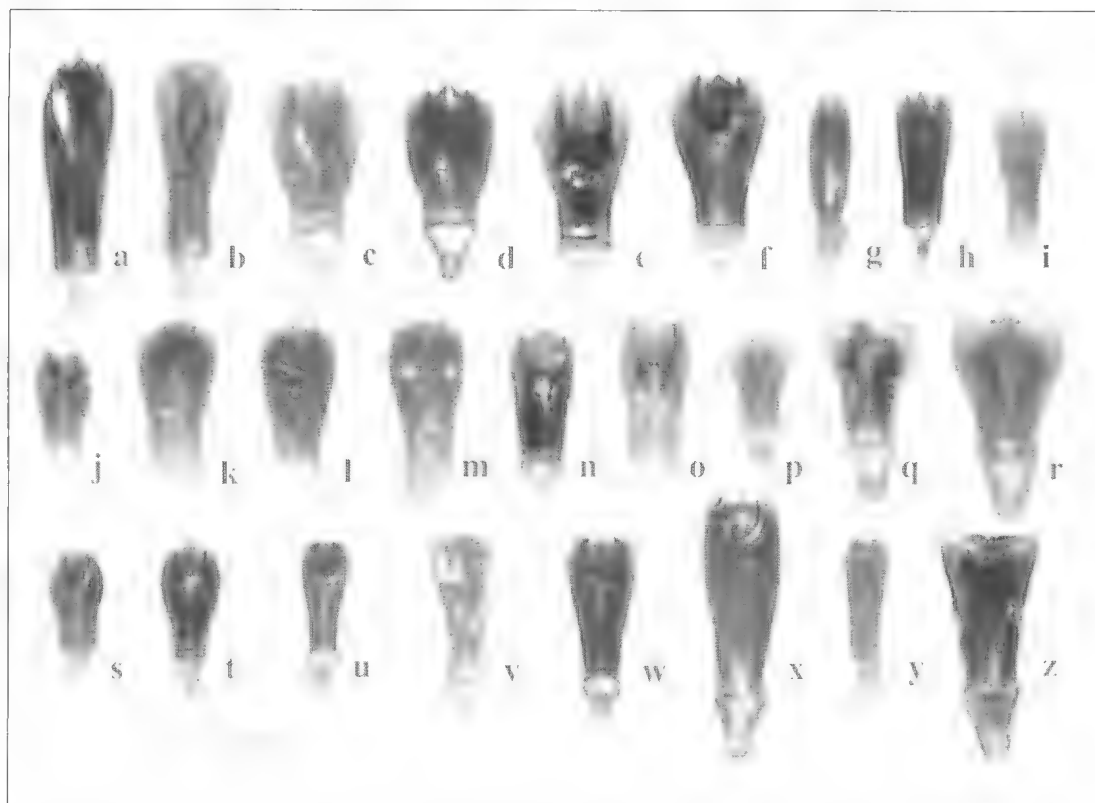


Fig 1. Male genitalia of the following species: a. *Castiarina simulata perplexa* (Hope) b. *C. darkinensis* sp. nov. c. *C. moxoni* sp. nov. d. *C. goudiana* (Barker) e. *C. pallida* sp. nov. f. *C. subnotata* (Carter) g. *Astraeus kitchini* sp. nov. h. *Castiarina kiatae* (Barker) i. *C. bilyi* sp. nov. j. *C. markgoldingi* sp. nov. k. *C. erasma* (Carter) l. *C. gardnerae* (Barker) m. *C. mustelamajor* (Thomson) n. *C. haswelli* (Carter) o. *C. denmanensis* sp. nov. p. *C. coalstounensis* sp. nov. q. *C. gilberti* sp. nov. r. *C. carinata* (Macleay) s. *C. chlorota* sp. nov. t. *C. balthasari* (Obenberger) u. *C. hugejiana* sp. nov. v. *C. parallela* (White) w. *C. vittata* (Saunders) x. *C. xanthopilosa* (Hope) y. *C. kitchini* sp. nov. z. *C. producta* (Saunders). Scale bar = 2 mm.

Paratypes

WA: ♂, Yellowdine, 16.x.2001, S. Bílý, PMCE; ♂, Queen Victoria Rock, Coolgardie, 1.xi.2001, S. Bílý, PMCE; ♂, same data as holotype, SAMA.

Size: Holotype, 8.8 x 3.2 mm. Males, 7.6 – 9.6 x 2.4 – 3.4 mm. Females, unknown.

Colour: Head, antennae and pronotum bronze with blue and purple reflections. Scutellum black with purple reflections. Elytra yellow with the following black markings with blue reflections: narrow band along basal margin, pre-medial fascia with ends projecting anteriorly meeting basal margin and posteriorly reaching lateral margin; post-medial meeting lateral margin; pre-apical spade-shaped mark, all marks connected along suture. Ventral surface and legs bronze. Setae silver.

Shape & sculpture: Elongate. Head punctured with

median sulcus. Antennae, antennomeres: 1-3 obconic; 4-11 triangular. Scutellum scutiform, without punctures, medially excavated. Pronotum punctured, anterior margin straight, basal margin bisinuate, median longitudinal impressed line ending in small basal fovea, laterally rounded out from base, rounded and narrowed to apex. Elytra punctate-striate, intervals faintly wrinkled, laterally angled outwards from base, rounded at humeral callus more or less parallel-sided until rounded post-medially, rounded and narrowed to bispinose apex, both spines sharp, margin deeply indented between, apical margin sub-serrate. Ventral surface densely setose. S7 truncate in males.

Aedeagus: Parameres elongate, barely expanded towards apex which is rounded; penis in form of a thin pointed rod (Fig. 1i).

Remarks

The colour and pattern of this species most resemble *Castiarina kiatae* (Barker, 1980), but male genitalia are quite distinct (Fig. 1h): the apex of the penis is pointed in *C. kiatae* and spine-like in *C. bilyi*. *C. kiatae* is a broader species.

Etymology

The species is named after my friend Dr S. Bily, its collector.

***Castiarina bugejana* sp. nov.**

(Figs 1u, 2i)

Holotype

♂, 48 km N Bourke, N.S.W., 9.ix.1984, on *Micromyrtus hexamera* flowers, A. Sundholm & J. Bugeja, SAMA I 21 554.

Allotype

♀, 48 km N Bourke, N.S.W., 24.viii.84, on *Micromyrtus hexamera* flowers, A. Sundholm & J. Bugeja, SAMA I 21 555.

Paratypes

NSW: ♂, same data as holotype, SAMA; 2 ♀♀, 5.ix.1986, 48 km N Bourke, on *Thryptomene hexamera*, A. Sundholm & J. Bugeja, ASSH; 7 ♂♂, ♀, Glengeera Station: 38 km N Bourke, NSW; 29° 44' 37.1" S, 145° 57' 9.9" E. Elev. 129 m, 6.ix.2003, on *Thryptomene hexamera* flowers, A. Scott, A. Sundholm, ASSH; 3 ♂♂, ♀, Ledknapper Crossing Road, 43.2 km N Bourke, NSW, 29° 45' 9.2" S, 146° 0' 32" E. Elev. 103 m., 6.ix.2003, on *Thryptomene hexamera* flowers, A. Scott, A. Sundholm, ASSH.

Size: Holotype, 9.6 x 3.2 mm. Males, 9.1 – 11.4 x 2.8 – 3.8 mm. Females, 10.4 – 11.8 x 3.2 – 4.0 mm.

Colour: Head, antennae, pronotum dull bronze. Scutellum bright copper-bronze. Elytra black with faint purple reflections and the following yellow spots on each elytron: four large in middle in a row from base to apex; two elongate along margin, the first beneath humeral callus, the second behind it. Ventral surface and legs bronze. Setae silver.

Shape and sculpture: Elongate. Head punctured, faint median sulcus. Antennae, antennomeres: 1-3 obconic; 4-11 triangular. Pronotum punctured, impressed medial line from base to anterior margin, anterior margin projecting medially, basal margin straight, lateral margin rounded from base to apex but not bulbous. Scutellum scutiform, without punctures, medially excavated. Elytra punctate-striate, 3rd interval from suture much larger than the rest, lateral intervals rough, inner smooth, laterally angled outwards from base, more or less parallel-

sided until rounded post-medially and narrowed to bispinose apex, both spines minute, margin indented between. Ventral surface and femora covered in flat feathery setae. *S*₇ truncate in males, rounded in females.

Aedeagus: Parameres slightly angled outwards from basal piece, broadened at middle and more or less parallel-sided until rounded at the apex, penis sharp (Fig. 1u). Proctiger in both sexes rounded and without notching.

Remarks

This species belongs in the *parallela* species group. Three other group member species occurring only to the east of the Nullarbor Plain are *Castiarina parallela* (White, 1859) (Fig. 1v), *Castiarina vittata* (Saunders, 1868) (Fig. 1w) and *Castiarina xanthopilosa* (Hope, 1847) (Fig. 1x). All have rounded proctigers unlike the species found in W.A. (Barker, 1996). *C. bugejana* is a very distinctive species having a dark background to the elytral pattern. *C. vittata* has two elongate vittae on the elytra and no spots. The other two species both have the same spotted pattern but the background colour in both is a dark red-brown.

Etymology

Named after my friend J. Bugeja, Sydney.

***Castiarina chlorota* sp. nov.**

(Figs 1s, 2c)

Holotype

♂, Northampton, W.A., 27.viii.1971, K. & E. Carnaby, ANIC.

Allotype

♀, same data as holotype, ANIC.

Paratypes

WA: 14 ♂♂ & ♀, Mingenew, 3.ix.1958, Le Souef, ANIC; 2 ♂♂ Mingenew, 28.viii.70, K. Carnaby, Brooks bequest, ANIC; 4 ♂♂ & ♀, Mingenew, 28.viii.70, K. & E. Carnaby, ANIC; 11 ♂♂, 7 ♀♀, Mingenew, 29.viii.70, ANIC; ♂ & 3 ♀♀, 8/70, K. C., Brooks bequest, ANIC; ♂ & ♀, 28.ix.1970, K. & E. Carnaby, ANIC; 3 ♂♂ & 2 ♀♀, Mingenew, 29.ix.1970, K. & E. Carnaby, SAMA; 22 ♂♂ & 22 ♀♀, same data as holotype, ANIC; 3 ♂♂ & ♀, 7.ix.1971, Mingenew, K. & E. Carnaby, ANIC; 2 ♂♂ & 2 ♀♀, Geraldton, 3.viii.1973, K. & E. Carnaby, ANIC; ♂ & 4 ♀♀, Mingenew, 22.viii.1974, K. & E. Carnaby, ANIC; ♂, 23 km E by N Dongara, 30.ix.1981, I. D. Naumann & J. C. Cardale, ANIC; ♀, H. W. Brown, Moore Riv., ANIC; ♀, no data, ANIC; ♂, 80 km S Northampton,

20.viii.78, M. Powell, MPWA; ♂, 30 km S Northampton, 26.viii.1979, on *Scholtzia* flowers, T. M. S. Hanlon, MHSA; ♂, 18 km S Three Springs, 20.xi.91, D. Knowles, MPWA; ♂, 4.x.1996, K. Kershaw, MPWA.

Size: Holotype, 7.8 x 2.4 mm. Males, 6.9 – 9.6 x 2.2 – 3.0 mm. Females, 7.6 – 11.2 x 2.4 – 4.0 mm.

Colour: Head, antennae, pronotum, scutellum green. Elytra dark red-brown with the following yellow markings: three circular, medial spots in a row on each elytron; a small round spot on margin at humeral callus and a similar medial one, an elongate preapical mark also on margin. Ventral surface and legs green. Setae silver.

Shape and sculpture: Head closely punctured, median sulcus, short muzzle. Antennae antennomeres: 1-3 obconic; 4-11 triangular. Pronotum closely punctured, narrow basal fovea extending forwards to middle as glabrous line, then to margin as impressed line, basal fovea on each side closer to margin than middle; apical margin projecting medially, basal margin barely bisinuate; laterally parallel-sided at base, angled outwards and rounded to widest medially, rounded to apex. Scutellum scutiform, glabrous, flat. Elytra punctate-striate, intervals convex, punctured and wrinkled, more so laterally than medially; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially, narrowed to bispinose apex; margin rounded and indented between spines, apices diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous; otherwise setose, setae flat, feathery. *S*₇ truncate in both sexes. Aedeagus: Angled outwards from basal piece, rounded to widest post-medially then converging towards apex. Penis broad with small blunt apex (Fig. 1s).

Remarks

C. chlorota belongs in the *parallela* species group and is closest to *C. balthasari* (Obenberger, 1928). They are easily separated because the aedeagi differ (Fig. 1t) and *C. chlorota* has a green head, pronotum and ventral surface, all brownish in the other species.

Etymology

The species is named for its colour: *chloros* Gr., green.

Castiarina coalstounensis sp. nov.

(Fig. 1p, 2j)

Holotype

♂, Coalstoun Lakes, Qld, 20.xi.01, D. Kitchin, SAM I 21 569.

Allotype

♀, same data as holotype, SAM I 21 570.

Paratypes

Qld: 4 ♂♂, same data as holotype, SAMA, DKQA.

Size: Holotype, 8.8 x 3.2 mm. Males, 8.8 – 9.4 x 3.2 – 3.3 mm. Females, 8.2 – 11.2 x 3.0 – 4.4 mm.

Colour: Head, antennae green-bronze. Pronotum green-bronze with dark blue medial area. Scutellum green-bronze or blue. Elytra with yellow background and the following black markings: narrow basal mark, pre-medial fascia reaching lateral margins, post medial fascia reaching lateral margins, pre-apical spade-shaped mark extended to cover spines, all marks connected along suture, apical margin red. Ventral surface blue and/or bronze-green. Legs blue. Setae silver.

Shape & sculpture: Head closely punctured with a deep median sulcus. Antennae: antennomeres 1-4 obconic; 5-11 toothed. Pronotum deeply punctured, deep median sulcus, anterior margin straight, basal margin bisinuate, laterally rounded from base to apex, widest before middle. Scutellum scutellate, punctured. Elytra punctate-striate, 3rd interval from suture raised, inner three intervals not as heavily punctured as all of the rest, laterally angled out from base, rounded at humeral callus, concave then rounded after middle to bispinose apex, both spines short, margin rounded and indented between. Ventral surface punctured and setose, setae moderately long and dense. *S*₇ truncate in both sexes. Legs 2-3: male tarsomeres 1-3 with single median spine replacing pulvilli.

Aedeagus: Wedge-shaped (Fig. 1p).

Remarks

This species is a member of the *sexplagiata* species group with typical male genitalia and modified tarsomeres on legs 2 & 3, closest to *Castiarina gilberti* sp. nov., but with different male genitalia (Fig. 1p).

Etymology

The species is named after the type locality, Coalstoun Lakes, Queensland.

Castiarina darkinensis sp. nov.

(Figs 1b, 2e)

Holotype

♂, 6 km W Little Darkin Swamp, W.A., 21.xii.00/3.i.01, to red bucket, Knowles & Powell, SAMA I 21 556.

Allotype

♀, same data as holotype, SAMA I 21 557.

Paratypes

WA: ♂ & 2 ♀ ♀, same data as holotype, MPWA.

Size: Holotype, 11.6 x 4.5 mm. Males, 11.2 – 11.6 x 4.4 – 4.5 mm. Females, 11.3 – 13.0 x 4.4 – 5.1 mm. Colour: Head, antennae and pronotum bronze. Scutellum dark blue with or without bronze reflections. Elytra with yellow background, faint red margin and the following black markings: basal margin; pre-medial fascia with ends projecting anteriorly and posteriorly and meeting margin; post-medial fascia meeting margin; pre-apical anchor-shaped mark, marks all connected along suture. Ventral surface and legs bronze.

Shape & sculpture: Head punctured, without median sulcus. Antennae, antennomeres: 1-3 obconic; 4-11 triangular. Pronotum heavily punctured, faint median impressed line from base to apex, apical margin projecting medially, basal margin faintly bisinuate, lateral margin concave at base then rounded outwards all the way to apical margin, bulbous. Scutellum scutiform, without punctures, medially excavated. Elytra punctate-striate, intervals punctured more so laterally than medially, laterally angled outwards from base, rounded at humeral callus faintly concave until rounded post-medially and narrowed to bispinose apex, sutural spine heavier than marginal spine, rounded between, apices diverging. Ventral surface heavily punctured, except margins of abdominal sclerites glabrous, densely setose. S₇ truncate in males, rounded in females.

Aedeagus: Elongate, parameres diverging slightly from base, abruptly rounded apically, penis sharp (Fig. 1b).

Remarks

This species is a member of the *simulata* species group. The colouration and pattern of the elytra is similar to that of *Castiarina simulata perplexa* (Hope, 1846) which also has a red margin. They can be distinguished by the anchor-shaped apical mark on the elytra, spade-shaped in *C. simulata perplexa* and the differences in male genitalia (Fig. 1a). All of the specimens were captured by using a colour lure.

Etymology

This species is named after the type locality, Darkin, W.A.

Castiarina denmanensis sp. nov.
(Figs 1o, 2h)

Holotype

♂, Mt Denman summit, N.S.W., S32.23.1 E150.39.27, 11/12.xii.200, on *Leptospermum* sp.

flowers, A. Sundholm, R. Chin, K. Tazoe, SAMA I 21 558.

Allotype

♀, same data as holotype, SAMA I 21 559.

Paratypes

NSW: 2 ♂ ♂, East Minto, 13.xii.66, G. Williams, ANIC; 4 ♂ ♂ & ♀, same data as holotype, ASSH; 5 ♂ ♂, Wolgan State Forest, 33° 15' 17" S, 150° 6' 16" E Elev 1051 m., 27.xii.2002, on flowers of *Leptospermum*, A. Scott, ASSH.

Size: Holotype, 12.4 x 4.6 mm. Males, 11.6 – 13.4 x 4.4 – 5.0 mm. Females, 13.7 – 14.2 x 3.8 – 4.9 mm. Colour: Head bronze with or without purple reflections. Antennae black, antennomeres 1-2 with green reflections. Pronotum bronze with or without purple reflections around the margin. Scutellum bronze with coppery reflections. Elytra basal colour yellow with red margins and the following black markings: band along basal margin; pre-medial fascia not reaching margin, ends expanded broadly forwards to meet anterior margin and narrowly posteriorly to meet margin enclosing a red spot on margin beneath humeral callus; broad post-medial fascia reaching margin; spade-shaped pre-apical mark, all marks connected along suture. Ventral surface: male coppery sternal segments, red-brown abdominal segments; female all coppery. Legs: dorsal surface greenish; ventral surface purple. Setae silver.

Shape and sculpture: Head punctured, shallow median sulcus. Antennae, antennomeres: 1-3 obconic; 4-11 triangular. Pronotum punctured, variable short median glabrous line near base, anterior margin projecting medially, basal margin bisinuate, laterally parallel-sided from base until middle then rounded to anterior margin. Scutellum scutiform, with few punctures. Elytra punctate-striate, intervals punctured, more so laterally than medially, laterally angled outwards from base, rounded at humeral callus then more or less parallel-sided until post-medially rounded and narrowed to bispinose apex, both spines small and sharp, margin rounded between. Ventral surface punctured, setae flattened and feathery. S₇ truncate in males, rounded in females.

Aedeagus: Parameres expanded apically, penis broad and pointed (Fig. 1o).

Remarks

This species most resembles *Castiarina haswelli* (Carter, 1916), an eastern Australian species. However, there are differences in colour, size and male genitalia. In *C. haswelli* the ventral surface in

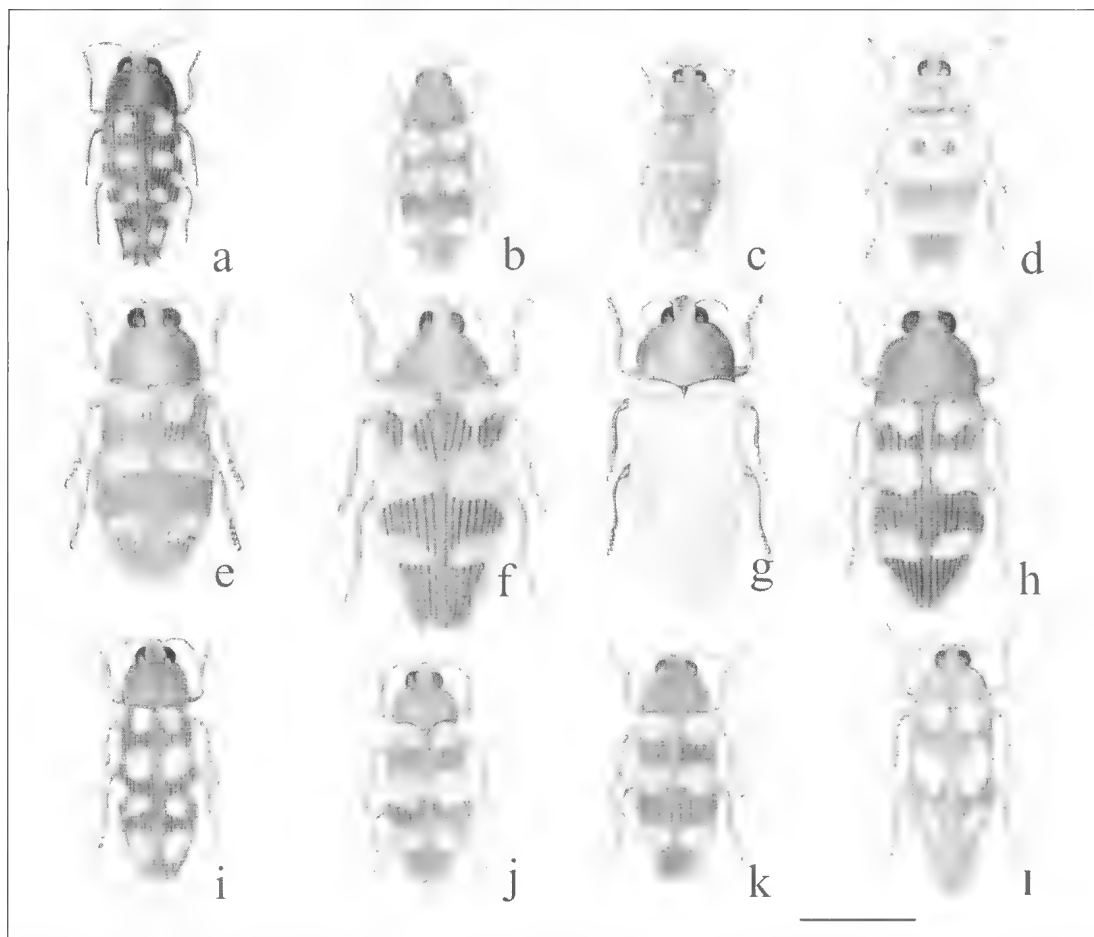


Fig 2. Habitus illustrations of the following species: a. *Astraeus kitchini* sp. nov. b. *Castiarina bilyi* sp. nov. c. *C. chlorota* sp. nov. d. *C. markgoldingi* sp. nov. e. *C. darkinensis* sp. nov. f. *C. moxoni* sp. nov. g. *C. pallida* sp. nov. h. *C. denmanensis* sp. nov. i. *C. bugejiana* sp. nov. j. *C. coalstounensis* sp. nov. k. *C. gilberti* sp. nov. l. *C. kitchini* sp. nov. Scale bar – 5 mm.

females is blue and in males red; it is a smaller species and male genitalia are different (Fig. 1n). The two specimens from East Minto have a paler elytral pattern than those from Mt Denman.

Etymology

The species is named after the type locality, Mt Denman, NSW.

Castiarina gilberti sp. nov.

(Figs 1q, 2k)

Holotype

♂, Blackdown Tableland, Expedition Ra., Qld, 9.xi.1981, S. Barker, P. Kempster, H. Vanderwoude, QMBA.

Allotype

♀, same data as holotype, SAMA I 21 561.

Paratypes

Qld: 4 ♂♂, same data as holotype, SAMA, QMBA; 2 ♂♂, Stony ck Falls, Blackdown Tbl, on *Melaleuca*, 25.x.2000, S. Barker, M. Powell, QMBA; ♂ & ♀, Blackdown Tableland, 24.xi.1999, on *Leptospermum* & *Eucalyptus*, T.M.S. Hanlon, MHSA.

Size: Holotype, 10.8 x 4.0 mm. Males, 9.3 – 11.0 mm x 3.5 – 4.0 mm. Females, 10.6 – 11.0 x 4.0 – 4.5 mm.

Colour: Head with blue apex, yellow green with violet reflections at base. Antennae blue. Pronotum

laterally blue, medially black with bronze reflections. Scutellum blue. Elytra yellow with red lateral margin and the following black markings with blue reflections: narrow basal margin, pre-medial fascia not reaching margin, ends expanded anteriorly; post-medial fascia reaching margin; mark covering apex and spines, all marks connected along suture. Ventral surface blue-green. Legs blue. Setae silver.

Shape and sculpture: Head closely punctured, broad median sulcus, short muzzle. Antennomeres 1-4 obconic, 5-11 toothed. Pronotum densely punctured, basal fovea extending forwards to apical margin as impressed line, basal notches on each side closer to margin than middle; apical margin straight, basal margin bisinuate; laterally angled outwards from base, rounded at widest part pre-medially, rounded and narrowed to apex. Scutellum scutiform, punctured, excavate. Elytra punctate-striate, 3rd interval from suture raised, intervals convex, heavily punctured; laterally angled out from base, rounded at humeral callus, concave, rounded post-medially and narrowed to bispinose apex; both spines small, margin rounded and indented between spines, apices hardly diverging. Ventral surface with shallow punctures, edges of abdominal segments glabrous, setose, setae short. S₇ truncate in both sexes. Males: legs 2 and 3 with pulvilli absent on tarsomeres 1-3, replaced by median spine.

Aedeagus: Wedge-shaped (Fig. 1q).

Remarks

C. gilberti sp. nov. is a typical member of the *sexplagiata* species group, the males of which have similar wedge-shaped male genitalia and reduced pulvilli on legs 2 and 3. The specimens were collected on the flowers of *Melaleuca lineariifolia* Smith and *Baeckea* sp. This species is closest to *Castiarina carinata* (Macleay, 1863), in which the elytra has darker brown background colour, no red lateral markings and male genitalia differ (Fig. 1r).

Etymology

The name honours the late John Gilbert, naturalist with the Leichhardt Expedition to Port Essington, which passed through the locality, Expedition Range, in 1842.

Castiarina kitchini sp. nov.
(Figs 1y, 2l)

Holotype

♂, Acacia Plateau, NSW, 26.i.2000, D. Kitchin, SAMA I 21 562.

Allotype

♀, same data as holotype, SAMA I 21 563.

Paratypes

NSW: 2 ♂♂, 2 ♀♀, Acacia Plateau, NSW, 20.i.2000, D. Kitchin, DKQA; 3 ♂♂, same data as holotype, DKQA. QLD: ♀, National Park, Macpherson Rge, i.28, H. J. Carter, ANIC.

Size: Holotype, 10.6 x 3.4 mm. Males, 10.6 – 11.2 x 3.2 – 3.8 mm. Females, 11.2 – 12.2 x 3.6 – 4.0 mm.

Colour: Head, green; antennae blue-green. Pronotum, scutellum green with yellow reflections. Elytra with yellow background and with the following black markings: pre-medial fascia with ends expanded anteriorly, but not reaching anterior margin, and posteriorly; post-medial fascia with ends expanded anteriorly meeting pre-medial fascia along the lateral margin; an arrow-shaped pre-apical mark covering apical spines, all marks connected along suture forming three yellow spots on each elytron, anterior and posterior with red lateral margin. Ventral surface green with yellow reflections. Legs royal blue, tarsi blue.

Shape and sculpture: Head shallowly punctured with prominent median sulcus. Antennomeres 1-3 obconic; 4-11 triangular. Pronotum shallowly punctured, with a faint median sulcus in form of a glabrous impunctate line from middle to near base ending in a deep basal fovea; anterior margin straight, basal margin bisinuate; laterally rounded out from base, rounded and tapered to apex. Scutellum scutiform, medially indented with a few punctures. Elytra punctate-striate, laterally angled out from base, rounded at humeral callus, then slightly concave until rounded post-medially and tapered to bispinose apex, marginal spine elongate, wide at base but pointed, sutural spine represented by notch. Ventral surface shallowly punctured, with long setae. S₇ rounded in both sexes.

Aedeagus: Elongate, expanded apically, penis sharp (Fig. 1y).

Remarks

This species is a member of the *producta* mimicry group and could be confused with that species but can be separated by having: antennomeres 1-4 obconic; a more prominent median sulcus and fovea on the pronotum which is rounded from base to apex; finer apical spines on the elytra; elongate aedeagus, not wedge-shaped as in *Castiarina producta* (Saunders, 1868) (Fig. 1z).

Etymology

The species is named after the collector, D. Kitchin, Toowoomba.

Castiarina markgoldingi sp. nov.
(Figs 1j, 2d)

Holotype

♂, km N Galena Bridge, W.A., on *Dicrastylis* sp., 14.xii.1996, Golding and Powell, SAMA I 21 564.

Allotype

♀, same data as holotype, SAMA I 21 565.

Paratypes

WA: ♀, 65 km N Galena Bridge, on *Dicrastylis*, 18.xii.93, MG & MP, MPWA.; ♀, 64 km N Galena Bridge, on *Dicrastylis* sp., 12.xii.1996, Golding & Powell, MPWA; ♀, 65 km N Galena Bridge, on *Dicrastylis* sp., 12.xii.1996, Golding & Powell, MPWA.

Size: Holotype, 9.1 x 3.4 mm. Females, 9.0 – 10.5 x 3.3 – 3.9 mm.

Colour: Head black with blue reflections. Antennae blue. Pronotum orange-brown with medial circular black spot, divided down middle and touching basal margin. Scutellum black. Elytra orange-brown with the following black markings: narrow basal margin projecting over humeral callus on each side; pre-medial spot on each side; post-medial fascia touching margin and suture, projecting anteriorly and posteriorly in middle of each side; mark covering apex and spines. Ventral surface: prosternum orange-brown; meso-sternum and metasternum dark blue; abdomen testaceous. Legs dark blue. Setae silver.

Shape and sculpture: Head closely punctured, broad median sulcus, short muzzle. Antennomeres 1-4 obconic, 5-11 toothed. Pronotum closely punctured, elongate basal fovea, basal notches represented by glabrous area on each side closer to margin than middle; apical margin concave, basal margin barely bisinuate; laterally angled outwards from base, rounded to widest before middle, tapered to apex; dorsal surface depressed one third distance from base. Scutellum scutiform, excavate, punctured. Elytra punctate-striate, intervals convex, punctured, 9th from suture raised and larger than rest; laterally angled out from base, rounded at humeral callus then parallel-sided, rounded post-medially and narrowed to bispinose apex; large sharp marginal spine, minute sutural spine, margin at first rounded then almost straight between spines, apices diverging, apical margin subserrate. Ventral surface with shallow punctures, edges of abdominal segments glabrous, otherwise moderately setose, setae medium length. S₇ truncate in males, rounded in females. Males: legs 2 and 3 tarsomeres 1-3 lacking pulvilli.

Aedeagus: Short, angled outwards from basal piece, rounded outwards before middle then more or less parallel-sided until rounded at apex. Penis broad with small spine (Fig. 1j).

Remarks

This species is grouped with *Castiarina mustelamajor* (Thomson, 1857) (Fig. 1m), *Castiarina erasma* (Carter, 1935) (Fig. 1k) and *Castiarina gardnerae* (Barker, 1987) (Fig. 1l), the males of which have modified tarsomeres and a similar body shape. *C. markgoldingi* differs from the rest in its colour and shape of male genitalia. All specimens were collected on the flowers of *Dicrastylis* sp.

Etymology

Named after the collector M. Golding, Beverley.

Castiarina moxoni sp.nov.

(Figs 1c, 2f)

Holotype

♂, 38 km ESE Amata, S.A., 26° 17' 45" S 131° 29' 32" E, 22.x.98, Pitjantjatjara Land Survey YURO7, SAMA I21 566.

Paratype

SA: ♂, same data as holotype, SAMA.

Size: Holotype, 13.6 x 5.3 mm. Males, 13.6 x 5.1 – 5.3 mm. Females, unknown.

Colour: Head, apex royal blue, medially black with blue reflections, basally black with bronze reflections. Antennomeres: 1-2 blue; 3-11 yellow-bronze. Pronotum black with bronze reflections medially, blue reflections laterally. Scutellum black. Elytra red with the following black markings: pre-medial fascia with ends expanded anteriorly and posteriorly but not reaching margin (in holotype fascia is broken leaving two medial spots), post-medial fascia reaching margin and spade-shaped pre-apical mark, all connected along suture, first two narrowly, second two broadly. Ventral surface black with blue and bronze reflections. Legs: femur and proximal dorsal section of tibia royal blue, distal and ventral section of tibia blue, tarsi blue-green. Shape and sculpture: Head punctured, with broad median sulcus from base to middle. Antennomeres: 1-3 obconic; 4-11 triangular. Pronotum punctured, anterior margin straight, basal margin bisinuate, laterally rounded and narrowed from base to apex. Scutellum scutiform, excavate, glabrous. Elytra punctate-striate, angled outwards from base, rounded at humeral callus, slightly concave rounded post-medially and tapered to bispinose apex, marginal and medial spines sharp and about equal length, margin rounded between spines. Ventral surface punctured, with moderate length setae mainly at sides. S₇ truncate in males.

Aedeagus: Short and broad apically. Penis sharp (Fig. 1c).

Remarks

This species could be confused with *Castiarina goudiana* (Barker, 1987)) (Fig. 1d). They are a similar colour and the elytral markings are similar. However, *C. moxoni* is a larger species, the aedeagus is broader and the punctuation on the head is denser than in the other species.

Etymology

The species is named to honour the late Moxon Simpson, Adelaide.

Castiarina pallida sp. nov.
(Figs 1e, 2 g)

Holotype

♂, Kilkivan, Qld, 14.xii.00, D. Kitchin, SAMA I 21 567.

Allotype

♀, same data as holotype, SAMA I 21 568.

Paratypes

Qld: 3 ♂♂ & ♀, same data as holotype, DKQA.

Size: Holotype, 13.0 x 4.6 mm. Males, 12.2 - 13.0 x 4.6 - 4.8 mm. Females, 13.8 - 14.4 x 5.3 - 5.4 mm.

Colour: Head green, with or without bronze reflections. Antennae green with yellow reflections. Pronotum and scutellum green with or without bronze reflections. Elytra with narrow green basal margin, remainder pale yellow with sub-serrate and apical spines black. Ventral surface and legs green with or without bronze reflections. Abdominal segments pale yellow with lateral light brown marks on each segment. Setae colourless.

Shape & sculpture: Head punctured, very broad median sulcus. Antennae, antennomeres: 1-3 obconic; 4-11 triangular. Pronotum punctured except for glabrous basal areas on each side midway between margin and middle, apical margin projecting medially, basal margin bisinuate, lateral margin angled out from base, rounded at humeral callus, more or less parallel-sided until rounded post-medially and narrowed to bispinose apices, both spines very small, margin indented and rounded between, apical margin sub-serrate. Ventral surface heavily punctured, sparse very short setae. S7 rounded in males, truncate in females.

Aedeagus: Short and broad, rounded apically, penis broad with small sharp point (Fig. 1e).

Remarks

C. pallida superficially resembles *Castiarina*

subnotata (Carter, 1933), but can be recognised by not having elytral spots, by the brown spotting on the abdominal segments and by having different male genitalia (Fig. 1f).

Etymology

This species is named for its pale colour: *pallidus* L. ashen.

Astraeus (s.s.) *kitchini* sp. nov.
(Figs 1g, 2a)

Holotype

♂, 30 km S Stanthorpe, Qld, 1.xi.2001, on *Casuarina cunninghamiana*, D. Kitchin, SAMA I 21 571.

Allotype

♀, same data as holotype, SAMA I 21 572.

Paratypes

Qld: 15 ♂♂ & 6 ♀♀, same data as holotype, DKQA, SAMA.

Size: Holotype, 8.4 x 3.2 mm. Males, 8.4 - 9.6 x 3.2 - 3.7 mm. Females, 9.2 - 11.2 x 3.3 - 4.0 mm.

Colour: Head mostly blue-green, basally green with yellow reflections. Antennae, antennomeres: 1 red-brown basally the rest green with yellow reflections; 2-11 blue-green. Pronotum green with yellow reflections. Elytra black, each elytron with seven irregular yellow spots, three along margin, four along suture. Ventral surface and legs blue-green. Setae silver.

Shape & sculpture: Head punctured and wrinkled, short median keel becoming a faint impressed line towards base, heavily setose. Antennomeres: apical segments same length in males; becoming progressively shorter in females. Pronotum heavily punctured, setose, with basal crypt. Elytra costate, intervals flat, punctured and wrinkled, laterally rounded from base, rounded post-medially and tapered to marginal spine, both spines well developed; humeral fold moderately developed, angled (Barker, 1975). Ventral surface: thoracic segments heavily punctured; abdominal segments lightly punctured. Ventral surface and legs setose.

Aedeagus: Unlike all other species in that laterally the parameres are curved from the basal piece to the apex.

Remarks

To my revised key to species of *Astraeus* (s.s.) (Barker, 1989) add new 17 Head and pronotum blue-green..... *kitchini* sp. nov.

Etymology

The species is named after the collector, D. Kitchin, Toowoomba.

Acknowledgements

I thank the following for their assistance: A.

McArthur, SAMA; M. Moulds, AMSA; T. A. Weir, ANIC; J. Bugeja, Sydney; M. Golding, Beverly; M. Powell, Melville; T. M. S. Hanlon, Sydney; D. Kitchin, Toowoomba; A. Sundholm, Sydney; the Simpson family of Adelaide for generous financial support; G. Williams, Lansdowne.

References

- ARNETT, R. H. Jr, SAMUELSON, G. A. & NISHIDA, G. M. (1993) 'The Insect and Spider collections of the World.' 2nd ed. (Sandhill Crane Press, Gainesville).
- BARKER, S. (1975) Revision of the genus *Astraeus* Laporte & Gory (Coleoptera: Buprestidae). *Trans. R. Soc. S. Aust.*, **99**, 105-142.
- _____ (1977) *Astraeus* (Coleoptera: Buprestidae): a description of three new species and new locality records. *Ibid.*, **101**, 11-14.
- _____ (1980) New species and new synonyms of *Stigmodera* (*Castiarina*) (Coleoptera: Buprestidae). *Ibid.*, **104**, 1-7.
- _____ (1987) Eighteen new species of *Stigmodera* (*Castiarina*) (Coleoptera: Buprestidae). *Ibid.*, **111**, 133-146.
- _____ (1989) Contributions to the taxonomy of Australian Buprestidae (Coleoptera): New species of *Astraeus* and *Stigmodera* (*Castiarina*) and a key to *Astraeus* (s.s.). *Ibid.*, **113**, 185-194.
- _____ (1996) Seventeen new species of *Castiarina* (Coleoptera: Buprestidae). *Ibid.*, **120**, 41-59.
- Carter, H. J. (1927) Australian Coleoptera: Notes and new species. No. v. *Proc. Linn. Soc. N.S.W.*, **52**, 222-234.
- _____ (1932) New Guinea and Australian Coleoptera. Notes and new species. No. 2. *Ibid.*, **57**, 101-115.
- _____ (1937) Some new Tenebrionidae in the South Australian Museum; together with notes and descriptions of other Australian Coleoptera. *Trans. R. Soc. S. Aust.*, **56**, 121-144.
- WATT, J. C. (1979) Abbreviations for entomological collections. *N. Z. Zool.* **6**, 519-520.

ADDITIONS TO THE MARINE ALGAL FLORA OF SOUTHERN AUSTRALIA

By H. B. S. WOMERSLEY¹

Summary

Womersley, H. B. S. (2004). Additions to the Marine Algal Flora of southern Australia. Trans. R. Soc. S. Aust. 128(2), 205-212, 30 November, 2004.

Following publication of “The Marine Benthic Flora of southern Australia”, four further new species are described, viz. *Sargassum flindersii*, *Ceramium adhaerens*, *C. wilsonii* and *Herposiphonia elegans*. All are deep water species.

Key Words: Marine Algal Flora, southern Australia, *Sargassum*, *Ceramium*, *Herposiphonia*.

ADDITIONS TO THE MARINE ALGAL FLORA OF SOUTHERN AUSTRALIA

by H. B. S. WOMERSLEY¹

Summary

WOMERSLEY, H. B. S. (2004). Additions to the Marine Algal Flora of southern Australia. *Trans. R. Soc. S. Aust.* 128(2), 205-212, 30 November, 2004.

Following publication of "The Marine Benthic Flora of southern Australia", four further new species are described, viz. *Sargassum flindersii*, *Ceramium adhaerens*, *C. wilsonii* and *Herposiphonia elegans*. All are deep water species.

KEY WORDS: Marine Algal Flora, southern Australia, *Sargassum*, *Ceramium*, *Herposiphonia*.

Introduction

Publication of "The Marine Benthic Flora of southern Australia" (Womersley 1984-2003), while covering over 1100 species of marine algae, left over 50 species excluded due to inadequate data on occurrence, reproduction, or discovery since the particular account of the group concerned.

Four distinctive deep water species are now described, most from the Isles of St Francis on the west coast of Eyre Peninsula, South Australia; three were listed but not described in the floristic account of Womersley & Baldock (2003).

Species Descriptions

Phylum Phaeophyta, Order Fucales

Sargassum flindersii Womersley, sp. nov.

FIGS 1-3

Thallus (Figs 1, 2) medium to dark brown, 10-30 cm high, with a terete, verrucose stipe 1-4 cm long and 2-4 mm in diameter, bearing apically several primary branches and attached by a discoid-conical holdfast 5-8 mm across, with 1-3 stipes; epilithic.

Primary branches (Fig. 2) 10-25 cm long, complanately and pinnately branched, alternately distichous in broader lower parts, less so in upper slenderer parts, with laterals (pinnae) alternately serrate; older primary branches lost leaving verrucose residues on the stipe. Axes flat, 2-3 (-4) mm broad below, bearing pinnae usually 2-6 mm apart, with a slight raised midrib; pinnae 2-3 cm long, serrations 1-2 mm long, mostly 1-2 mm apart, with scattered cryptostomata usually single on each side of midrib. Upper axes slender, becoming terete, 200-300 µm broad, with slender, flat, serrate pinnae 0.5-1 mm broad. Vesicles absent.

Reproduction. Thalli monoecious. Receptacles (Fig. 3) single or in small groups, terete, 400-1000 µm long and 300-500 µm in diameter, surface smooth to slightly verrucose. Conceptacles bisexual, ostioles scattered. Oogonia sessile, ovoid, 35-55 µm in diameter; antheridia in groups, single from a basal cell, elongate-ovoid, 5-8 µm in diameter.

Thallus 10-30 cm altus, stipes teres, verrucosus, 1-4 cm longus, 2-4 mm diam., ramis aliquot primariis 10-25 cm longis, complanate et pinnatim ramosis, ramis inferioribus lateralibus alterne distichis, 2-3 (-4) mm latis, serratis, cum costa exigua, rami superiores graciles, de crescentes, 200-300 µm diam., pinnis gracilibus planis serratis 0.5-1 mm latis. Vesiculae absentes.

Thalli monoecii. Receptacula singularia vel aggregata, teretia, 400-1000 µm longa et 300-500 µm diam., laevia ad parum verrucosa. Conceptacula bisexualia, ostiola dispersa.

Type from "The Hotspot", W of Flinders I., S. Aust., 32 m deep (Branden, 21.vi.1988), holotype and 2 isotype sheets in AD, A59294.

Distribution

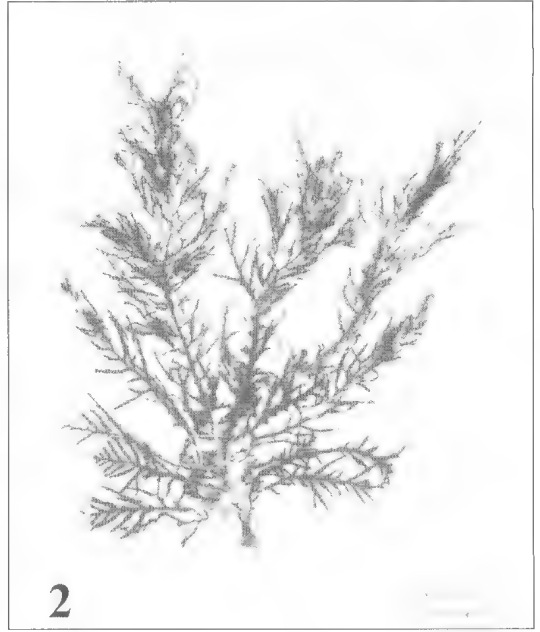
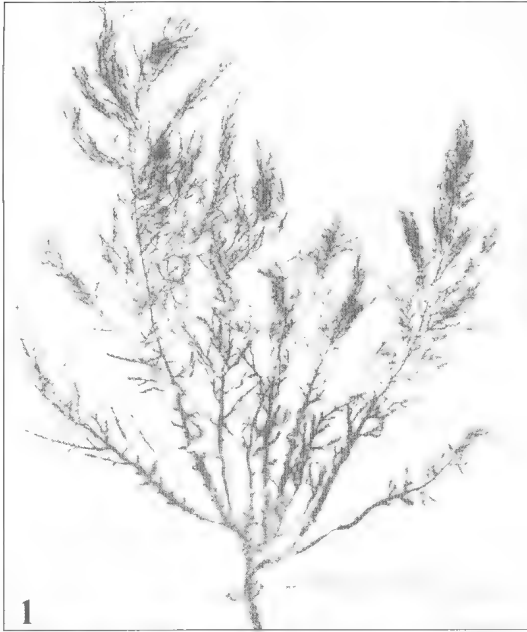
As well as the type, known from Egg I., Isles of St. Francis, S. Aust., 32-38 m deep (Shepherd, 11.i.1971; AD, A38033).

As is typical of species of subgenus *Phyllotrichia* of *Sargassum*, *S. flindersii* has a well-developed stipe bearing apically and seasonally primary branches which are basally pinnate with flat branches, and which develop slenderer upper branches with maturity which bear receptacles.

The June (1988) collection has upper slender branches bearing receptacles, whereas the Jan. (1971) collections have only the lower, sterile, pinnate branches. The length of and verrucose residues on the stipes indicate that the thalli may be several years old.

S. flindersii differs from previously described Australian species of *Phyllotrichia* (see Womersley 1954 and 1987) in the form and dimensions of the

¹ State Herbarium of South Australia, Plant Biodiversity Centre, Hackney Road, Hackney, S. Aust. 5069 and Dept of Environmental Biology, The University of Adelaide.



Figs 1–3. *Sargassum flindersii* (AD, A59294). Fig. 1. Habit, holotype. Fig. 2. Habit, isotype, showing pinnate primary branches. Fig. 3. Receptacles on upper branches.

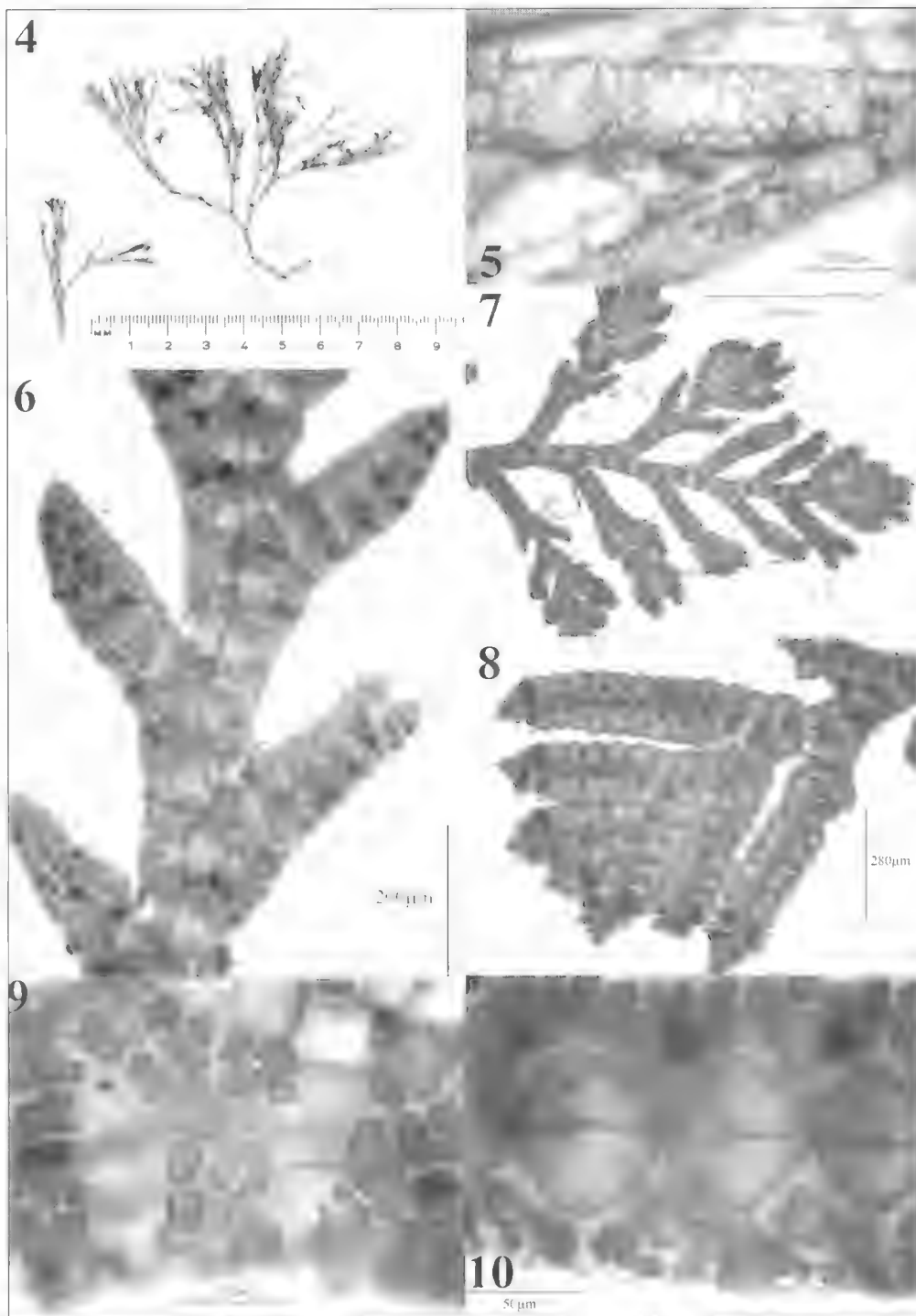
primary branches, in the position and form of the receptacles, and in the lack of vesicles (in all known plants). In the key in Womersley 1987, p. 420, it would separate in dichotomy 5.

Phylum Rhodophyta, Order Ceramiales, Family Ceramiaceae

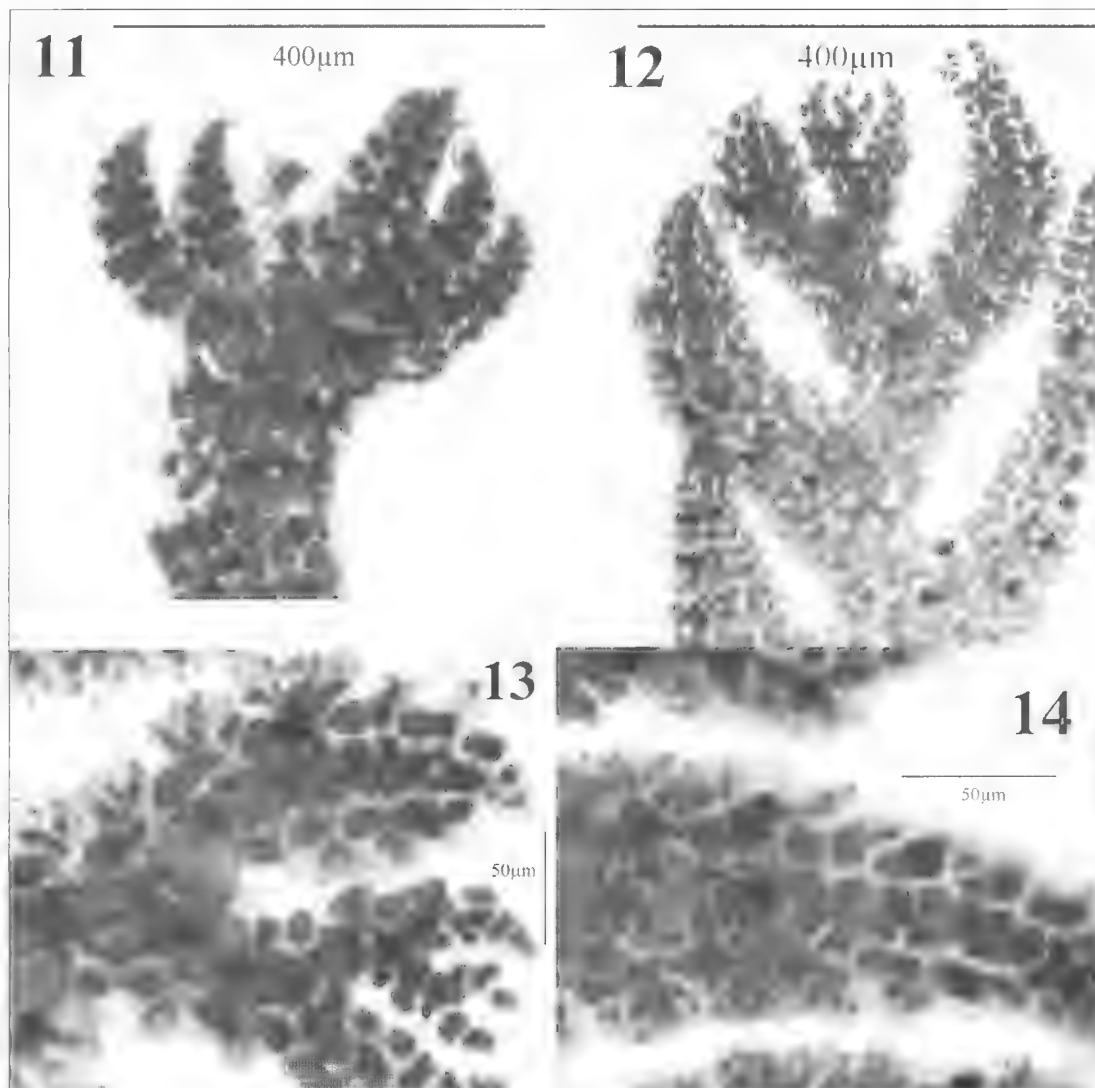
Ceramium adhaerens Womersley, sp. nov.

FIGS 4–14

Thallus (Figs 4–7) medium red, completely prostrate and adherent to the host (*Amphiroa* spp.), axes distichously and alternately branched sympodially (Figs 12, 13) 2 axial cells apart, branches slightly compressed, apices straight to slightly curved (Fig. 6), tapering abruptly, lateral branches simple or branched 2–4 cells apart (Fig. 7); internodal spaces present throughout, often and in older parts less so on margins resulting in an oval space in surface view (Figs 6,9); attachment of occasional axial cells by rhizoids cut off from periaxial cells and with digitate haptera. Axes 1–3 mm long and 130–180 μ m broad, laterals 200–600 μ m long and 90–140 μ m broad, more irregularly branched (1–4 cells apart). *Structure*. Periaxial cells 4, cut off close to apices, 2 laterally (Fig. 10) and 2 transversely in the compressed (ovoid in cross section) branches. Axial cells (Fig. 10) isodiametric, cytoplasm ovoid to $\frac{1}{2}$ 2 in older parts, gelatinous wall over cortical cells thick. Nodal bands (Figs 9, 10) 4–6 cells and 40–140 μ m broad, the periaxial cells cutting off laterally then outwardly branched chains 2–4 cells long, both acropetally and



Figs 4–10. *Ceramium adhaerens* (AD, A69339). Fig. 4. The holotype sheet, on *Amphiroa gracilis*. Fig. 5. *C. adhaerens* on the host. Fig. 6. A young branch with alternate laterals and some cells gland-like (with dark contents). Fig. 7. A branch with laterals bearing tetrasporangia. Fig. 8. Branches with opposite tetrasporangia. Fig. 9. Cortication on axial cells, surface view. Fig. 10. Cortication on axial cells, sectional view.



Figs 11–14. *Ceramium adhaerens* (MELU, Gen 9714; AD, A70205). Fig. 11. Female plant with remains (?) of carposporophyte surrounded by 5 subtending branchlets. Fig. 12. Spermatangial apex showing sympodial branching and darkly stained “gland” cells. Fig. 13. Sympodial apex with spermatangia cut off from cortical cells. Fig. 14. Branch with spermatangia.

basipetally, longer on the sides of branches where they largely close the space (Fig. 9); occasional outer cortical cells become gland-like (Figs 6, 9) with darkly-staining, even contents. Rhodoplasts elongate and longitudinal in axial cells, discoid to slightly elongate in cortical cells.

Reproduction. Apparently dioecious. Young carposporophyte (Fig. 11) with 4 – 5 stout subtending branchlets, mature ones not observed. Spermatangia (Figs 12–14) covering young branches on all sides, cut off from outer cortical cells.

Tetrasporangial branches (Fig. 8) 250 – 550 µm long and 120 – 160 µm broad, often clustered near apex of lateral branches. Tetrasporangia cut off from the lateral periaxial cells in 2 rows, only those near the tip of fertile branches retained, largely enclosed by involucre cells of the outer cortex, 35–55 µm in diameter, cruciately or tetrahedrally divided.

Thallus omnino prostratus et hospite (Amphiroa spp) adhaerens, axes 1 – 3 mm longi, alternatim distichi, ramosi in quaque 2 cellula, rami leviter compressi, 130 – 180 µm lati, apices recti,

decrecentes, rami laterales 200–600 μm longi et 90–140 μm lati, simplices vel ramosi 2–4 cellulis distantes; spatia internodales omnino praesentia, angustiora in marginibus spatium ovalim efficientia, interdum rhizoidea, e cellulis periaxialibus abscissa, haptera digitata cellulae pariaxiales 4, fasciatae nodales 4–6 et 40–140 μm latae, cellulae pariaxiales scindentes catenas ramosas cellularum corticalium 2–4 cellulas longas, et acropetale vel basifuge, aliquot cellulae glandulosae.

Reproductio. Gametophyta dioecii. Rami tetrasporangiales 250–550 μm longi et 120–160 μm lati, tetrasporangia in 2 seriebus, e cellulis lateralibus periaxialibus abscissa, 35–55 μm diam., vel cruciatim vel tetraedrice divisa, cellulis exterioribus corticalibus involucri magnopere inclusa.

Type from west coast of St Francis I., Nuyts Arch., S. Aust., 20 m deep, on *Amphiroa gracilis* (Shepherd, 16.ii.2002); holotype sheet in AD, A69339.

Distribution. Hillarys Boat Harbour and Rottnest I., W. Aust. to Pearson I., S. Aust.

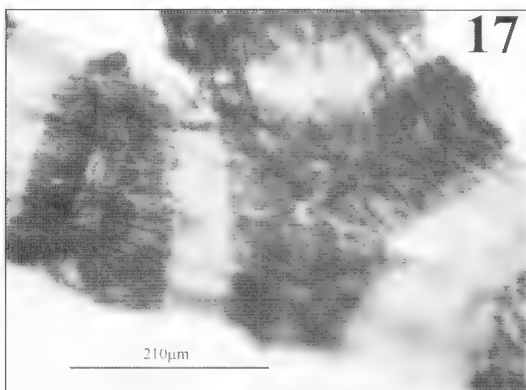
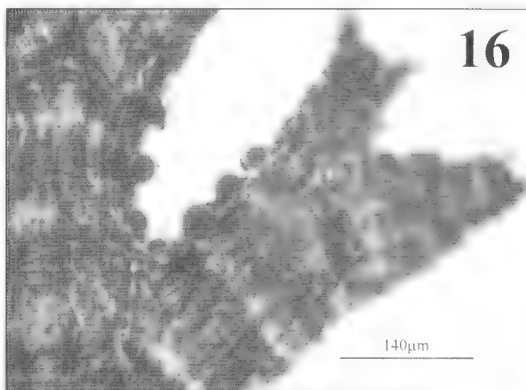
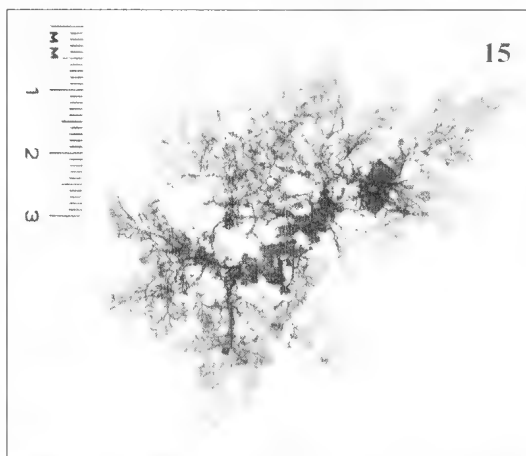
Known specimens. Off Hillarys Boat Harbour, Sorrento, W. Aust., 6 m deep on *Amphiroa anceps* (AIMS-NCI, Q66C-2614-I, 12.iii.1989, AD, A70206). Roe Reef, Rottnest I., W. Aust., 12–15 m deep on *A. anceps* (Kraft, Saunders & Millar, 2.ii.1994; MELU, GEN 9714; AD, A70205). Twin Rocks, Head of Great Australian Bight, S. Aust., 20–22 m deep on *A. anceps* (Branden, 19.i.1991; AD, A61151). East Point, St Francis I., Nuyts Arch., S. Aust., 17–18 m deep on *A. anceps* (Baldock, 21.ii.2002; AD, A69647 and 5–10 and 10–15 m deep on *A. anceps* (Baldock, 17.ii.2002; AD, A70210 and A70211). Pearson I., S. Aust., 22 m deep on *A. anceps* (Shepherd, 12.i.1969; AD, A70208).

C. adhaerens is apparently a deep-water species confined to the coralline alga *Amphiroa*, and is probably more widely distributed in the western part of southern Australia than indicated above. It is probably the only completely prostrate species of *Ceramium*, with *C. prostratum* Dawson (1963: 13, pl. 4, figs 10, 11) from the Galapagos being nearest in habit but quite distinct structurally.

***Ceramium wilsonii* Womersley, sp. nov.**

FIGS 15–18

Thallus (Fig. 15) medium red, erect, 2–4 cm high, alternately and probably largely complanately branched at intervals of 3–4 cells, apices straight and tapering abruptly to a point (Fig. 16). Nodal cortical bands (Fig. 17) separated by clear spaces throughout, spaces becoming as long or slightly longer than nodal bands. Probably epiphytic, attached by rhizoids. *Structure.* Branches 400–600 μm in diameter below, tapering slightly to 150–250 μm



Figs 15–17. *Ceramium wilsonii* (MEL, 45466). Fig. 15. The holotype. Fig. 16. Branch apices and tetrasporangia. Fig. 17. Nodal cortication.

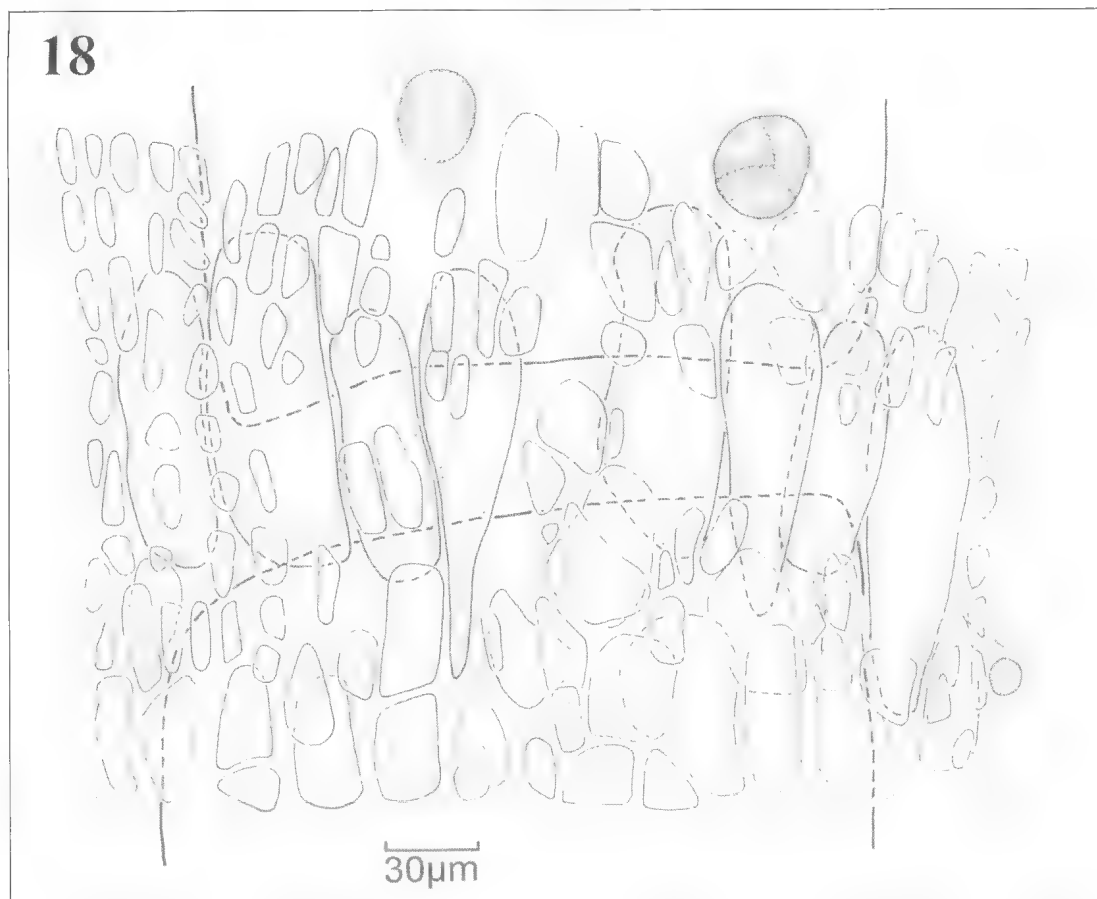


Fig. 18. *Ceramium wilsonii* (MEL, 45466, slide in AD). Drawing of nodal cortication (from dried/re-soaked specimen, probably incomplete for all cortical cells).

in diameter just below the apices, then abruptly to the conical apical cells 10 - 15 µm in basal diameter. Axial cells $\frac{1}{D}$ (0.7-) 1 - 1.5 when mature, with about 10 periaxial cells (Fig. 18), possibly including some pseudoperiaxial cells, each cutting off cortical cells both acropetally and basipetally with the nodes becoming (6-) 8 - 10 cells long (Figs 17, 18); most cortical cells cut off smaller outer cells mostly around their margins, some cells becoming gland-like with uniform darkly-staining contents. Rhizoids cut off from periaxial cells.

Reproduction. Carposporophytes borne on upper branches, 100 - 150 µm across, with 3 or 4 short subtending branchlets. Spermatangia unknown.

Tetrasporangia (Figs 16, 18) scattered on the nodal cortex, cut off from cortical cells, external and without any involucre, subspherical, 35 - 55 µm in diameter, tetrahedrally divided.

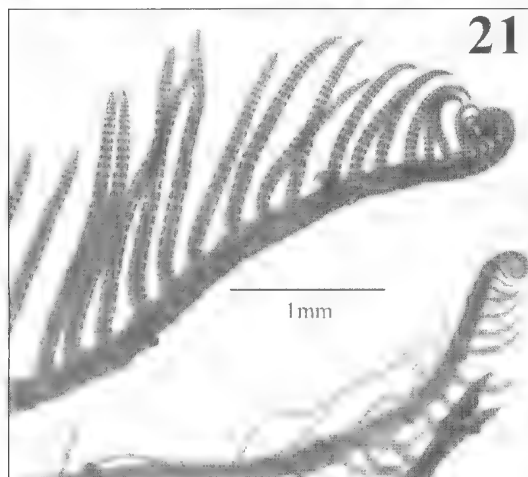
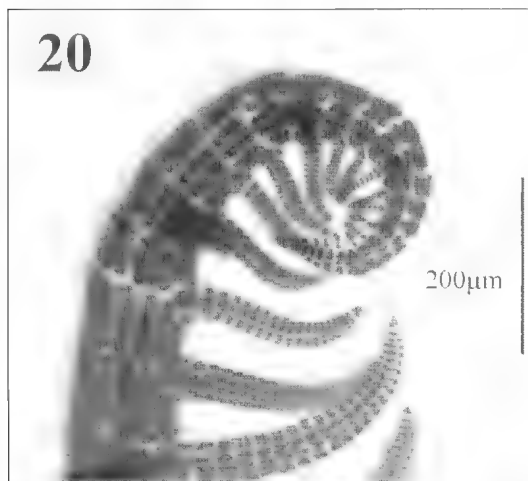
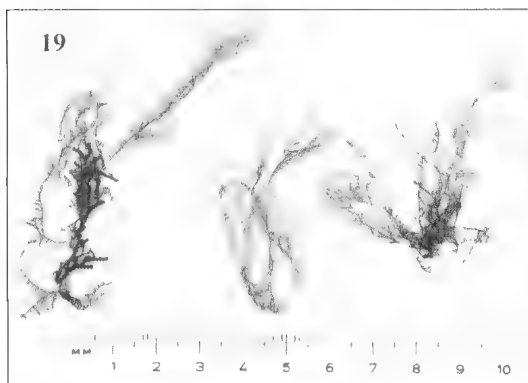
Thallus erectus, alternatim et magnopere complanate ramosus 3 - 4 cellulis separatus, apices

rectae, ad punctum abrupte decrescentes, rami inferiores 400 - 600 µm diam., rami superiores 150-250 µm diam., spatia internodalia ubique praesentia, cellulac axiales $\frac{1}{D}$ (0.7-) 1-1.5. Cellulae periaxiales circum 10 (fortasse cellulas pseudo-periaxiales includentes), abscindentes cellulas corticales et acropetale vel basifuge, nodi (6-) 8 - 10 cellulas longi crescentes, minoribus et exterioribus corticalibus cellulis, aliquot glandulosis.

Reproductio. Carposporophyta in ramis altioribus, 100 - 150 µm lata, cum 3 vel 4 brevibus subtensis ramulis. Spermatangia non nota. Tetrasporangia in cortice nodali sparsa, externa, non involucrata, 35 - 55 µm diam., tetraedrice divisa.

Type from Port Phillip Heads, Vic. *J.B. Wilson*, 4.ii.1889; holotype in MEL, 45466, tetrasporangial. Paratypes, same locality and collector, 28.i.1886 (NSW, 138572) and Western Port, Vic. *J.B. Wilson*, 8.i.1885; MEL, 45467, cystocarpic.

Distribution. Only known from the above collections.



Figs 19–21. *Herposiphonia elegans* (AD, A38074). Fig. 19. Specimens on holotype sheet. Fig. 20. Revolute apex of indeterminate branch with determinate laterals without trichoblasts. Fig. 21. Indeterminate branches with determinate laterals of uniform height; rhizoids on lower specimen.

C. wilsonii is distinguished by the apparently complanate and alternate branching pattern, the moderately robust habit, the nodal bands with outer cortical and gland cells, and the scattered, naked (non involucrate) tetrasporangia. In these features it is distinct from all other southern Australian species (see Womersley 1998, pp. 382 on). *C. wilsonii* shows some resemblance to *C. lentiforme* Millar (1990, p. 391, Figs 41A–C, 43A) from eastern Australia, which differs in having slightly curved apices, longer axial cells, lenticular spaces between the nodal cortication and branching about 6 axial cells apart; tetrasporangia were not recorded in this species, which is similar to *C. subdichotomum* W.v. Bosse (1923, p. 333, Fig. p. 334) (see South & Skelton 2000, p. 78, Figs 74–79), included under *C. borneense* W.v. Bosse in Abbott (1999, p. 267).

The Wilson specimens had been identified as *C. miniatum* Suhr, a name which applies to a South American species but is invalid (see Womersley 1978, p. 240).

Phylum Rhodophyta, Order Ceramiales, Family Rhodomelaceae

Herposiphonia elegans Womersley, sp. nov.

FIGS 19–21

Thallus (Fig. 19) with extensive, largely prostrate, sparsely branched, indeterminate primary branches, loosely attached, bearing dorsally from every segment, simple, erect, determinate laterals of uniform height (Fig. 20) in series of 3 separated by short, mostly dormant indeterminate laterals on the fourth segment on alternate sides. Attachment of indeterminate branches by rhizoids cut off from ventral pericentral cells, apparently growing on the bryozoan *Calpidium* in deep water. *Structure*. Apices of indeterminate branches dorsally revolute (Figs 20, 21), without trichoblasts, apical cells 15–20 μm in basal diameter with an oblique basal wall. Mature indeterminate branches 200–300 μm in diameter, pericentral cells usually 12, segments $\frac{1}{10}$ 0.6–0.8. Determinate laterals linear, 1–2.4 mm high, mostly of uniform height along a primary branch, 80–120 μm in diameter with segments $\frac{1}{10}$ 0.3–0.5, with (10–) 11 (–12) pericentral cells, tapering over the upper few segments to a conical apical cell 12–16 μm in basal diameter; trichoblasts absent. Rhizoids cut off from a lower pericentral cell, 20–60 μm in diameter, with a digitate hapteron becoming multi-cellular. Rhodoplasts discoid, scattered.

Reproduction. Unknown.

Thallus cum ramis extensis magnopere prostratis, sparsim ramosis indeterminatis, laxe affixis, ferentibus dorsaliter ex omnibus segmentis laterales simplices, erectos determinatos aequae altos, in serie trium separatos per laterales breves indeterminatos;

affixus per rhizoidea e cellulis ventralibus et pericentralibus; epizoicus in bryozoan. Rami indeterminati cum apicibus dorsaliter revolutis, sine trichoblastis; rami maturi indeterminate 200 – 300 μm diam., segmenta $\frac{1}{2}$ 0.6 – 0.8, cellulae pericentrales plerumque 12. Laterales determinati lineares, 1 – 2.4 mm longi, 80 – 120 μm diam., segmenta $\frac{1}{2}$ 0.3 – 0.5, cum (10-)11(-12) cellulis pericentralibus, cellula conica et apicali; trichoblasti absentes.

Reproductio non nota.

Type specimen. St Francis I., Isles of St Francis, S. Aust., 55 m deep on SW face (*Shepherd*, 9.i.1971); holotype sheet, AD, A38074.

Distribution. Only known from the holotype sheet. While only known from the one sterile collection,

H. elegans appears to be a distinctive deep-water species based on habit, dimensions and lack of trichoblasts. The only other species of *Herposiphonia* lacking trichoblasts appears to be *H. nuda* Hollenberg (1968, p. 548), which is a considerably slenderer species with fewer pericentral cells.

Acknowledgements

This study was carried out with the facilities of the State Herbarium of South Australia. Digital photography was carried out by Bob Baldock and Latin diagnoses provided by Mary Marlow, to whom appreciation is expressed. Dr Gerry Kraft kindly contributed sexual material of *C. adhaerens* and Dr Paul Silva clarified existing specific names of the genera involved.

References

- ABBOTT, I. A. (1999) Marine Red Algae of the Hawaiian Islands. (Bishop Museum Press, Honolulu).
- DAWSON, E. Y. (1963) New records of marine Algae from the Galapagos Islands. *Pacific Naturalist* **4**, 2-23.
- HOLLENBERG, G. J. (1968) An account of the species of the red alga *Herposiphonia* occurring in the central and western tropical Pacific Ocean. *Pacific Sci.* **22**, 536-559.
- MILLAR, A. J. K. (1990) Marine Red Algae of the Coffs Harbour Region, northern New South Wales. *Aust. Syst. Bot.* **3**, 293-593.
- SOUTH, G. R. & SKELTON, P. A. (2000) A review of *Ceramium* (Rhodophyceae, Ceramiales) from Fiji and Samoa, South Pacific. *Micronesica* **33**, 45-98.
- WEBER VAN BOSSE, A. (1923) Liste des algues du Siboga. II. Rhodophyceae. 2. Ceramiales. *Siboga-Exped. Monogr.* **59**, 311-392, pls 9, 10.
- WOMERSLEY, H. B. S. (1954) Australian species of *Sargassum*, subgenus *Phyllotrichia*. *Aust. J. Bot.* **2**, 337-354, pls 1-5.
- (1978). Southern Australian species of *Ceramium* Roth (Rhodophyta). *Aust. J. Mar. Freshw. Res.* **29**, 205-257.
- (1984) "The Marine Benthic Flora of southern Australia." Part I. (Handbook of the Flora and Fauna of South Australia. Govt Printer: Adelaide.)
- (1987) "The Marine Benthic Flora of southern Australia." Part II. (S. Aust. Govt. Printing Division, Adelaide.)
- (1994) "The Marine Benthic Flora of southern Australia". Part IIIA. Flora of Aust. Supp. Ser. Number 1. (ABRS: Canberra.)
- (1996) "The Marine Benthic Flora of southern Australia". Part IIIB. Flora of Aust. Supp. Ser. Number 5. (ABRS: Canberra.)
- (1998) "The Marine Benthic Flora of southern Australia." Part IIIC. (Dept. Envir. Herit. And Abor. Affairs, Adelaide.)
- (2003) "The Marine Benthic Flora of southern Australia." Part IIID. (A.B.R.S., Canberra and State Herbarium S. Aust, Adelaide.)
- & BALDOCK, R. N. (2003) The Encounter 2002 Expedition to the Isles of St Francis, South Australia. Marine Benthic Algae. *Trans. R. Soc. S. Aust.* **127**(2), 141-151.

THE USE OF EMERGENCE AS AN END-POINT FOR SEDIMENT TOXICITY TESTS USING THE AUSTRALIAN CHIRONOMID CHIRONOMUS MADDENI

By B. P. C. SMITH†‡ & M. KOKKINN§*

Summary

Smith, B. P. C. & Kokkinn, M. The use of emergence as an end-point for sediment toxicity tests using the Australian chironomid *Chironomus maddeni*. Trans. R. Soc. S. Aust. 128(2), 213-218, 30 November, 2004.

Growth reduction or retardation is used widely as an end-point in chronic toxicity studies. How this relates to the response of organisms in real ecological systems has been questioned. This study looks at the use of adult emergence and adult dry weight as alternative end-points for sediment toxicity tests with *C. maddeni*. Adult emergence was seen to be a sensitive indicator of toxicity and appears to be a more sensitive end-point than larval growth. In addition, it is a more biologically realistic end-point because it integrates toxic effects on all stages of chironomid life history.

Key Words: Emergence, Sediment toxicity, *Chironomus maddeni*.

THE USE OF EMERGENCE AS AN END-POINT FOR SEDIMENT TOXICITY TESTS USING THE AUSTRALIAN CHIRONOMID *CHIRONOMUS MADDENI*

by B. P. C. SMITH^{*†} & M. KOKKINN[§]

Summary

SMITH, B. P. C. & KOKKINN, M. The use of emergence as an end-point for sediment toxicity tests using the Australian chironomid *Chironomus maddeni*. *Trans. R. Soc. S. Aust.* 128(2), 213-218, 30 November, 2004.

Growth reduction or retardation is used widely as an end-point in chronic toxicity studies. How this relates to the response of organisms in real ecological systems has been questioned. This study looks at the use of adult emergence and adult dry weight as alternative end-points for sediment toxicity tests with *C. maddeni*. Adult emergence was seen to be a sensitive indicator of toxicity and appears to be a more sensitive end-point than larval growth. In addition, it is a more biologically realistic end-point because it integrates toxic effects on all stages of chironomid life history.

KEY WORDS: Emergence, Sediment toxicity, *Chironomus maddeni*.

Introduction

The lack of toxicity tests using Australian native species has been highlighted in a number of studies (Chapman 1995, Norris & Norris 1995, Brown 1993). To address this problem, a test method based on the USEPA's protocol for bulk sediment testing with *Chironomus tentans* (USEPA 1994) was adapted by Smith *et al.* (1999) for use with the native chironomid, *Chironomus maddeni* Martin & Cranston.

Both the USEPA and Smith *et al.* (1999) methods assess the effect of test sediments on larval growth and survival. While the lethality endpoint is readily interpreted, the sublethal endpoint of growth reduction or retardation is more difficult to assess and interpret. It is not known, for example, whether a statistically significant retardation in larval growth will adversely affect adult population dynamics and abundances (Liber *et al.* 1996). Natural variation in larval size and mass of same instar larvae has been observed in *C. maddeni* (Madden, C. 1997, pers. comm.) and may confuse the interpretation of growth reduction as an effect of sediment toxicity. In addition, the recovery of individuals after exposure and the determinations of size and mass are difficult and subject to error.

In response to the difficulties of using growth, adult emergence and adult dry weight presented themselves as alternative end-points for sediment

toxicity tests with *C. maddeni*. As a pointer to this investigation, lower numbers of emerging adults have been observed following the exposure of larvae to sediments contaminated with heavy metals (Wentzel *et al.* 1978), and emergence has been indicated as a possible end-point in other studies (e.g. ASTM 1993, Watts & Pascoe 1996).

Consequently, this work set out to correlate growth and mortality end-points with adult emergence and adult dry weight using sediments with known contaminants with the aim of making an assessment of emergence as a preferable end-point to larval growth.

Methods

Culture methods for *C. maddeni*

C. maddeni was cultured according to the methods described by Smith *et al.* (1999).

Test sediments

Test sediments were collected from two polluted and one unpolluted site (Table 1) within the Barker Inlet Wetland, Adelaide, South Australia. Sites were selected on the basis of toxicity assays conducted by Smith *et al.* (1999) and heavy metal contamination data for the area (Jenkins *et al.* 1997). Ten cores were taken within a 1 m radius at each sample site using a plastic hand-held suction corer and the top 10 cm of sediment from each core pooled in accordance with ASTM (1993) recommendations. Samples were stored in the dark at $4 \pm 1^\circ\text{C}$ and homogenised prior to use in tests. Tests were initiated within 14 days of collection

Growth Tests

Growth tests were performed according to the protocol developed by Smith *et al.* (1999). A total of

* Department of Biology, University of Toronto at Mississauga, 3359 Mississauga Road, Mississauga, Ontario L5L 1C6, Canada

† School of Pharmacy and Medical Sciences, University of South Australia, North Terrace, Adelaide, South Australia, Australia 5000

§ Author for correspondence

† Alternate address: ChemComm Enterprises, 163 route du Léman, 74160 Archamps, France

E-mail: bpcsmith101@hotmail.com or geocrinia101@yahoo.com.au

TABLE 1. Mean dry weight of *C. maddeni* larvae exposed to contaminated and reference sediment from the Barker Inlet Wetland. Data obtained from Smith et al. (1999).

Test Number	Date of Test	Sediment Type	% Survival	Mean larval dry weight (mg) S. D. shown in parentheses	T - value (1-tailed)
Test 1	19/03/97	Site 1 (Control)	95	0.546 (0.095)	4.862
		Site 2	90	0.114 (0.007)	
Test 2	15/04/97	Site 1 (Control)	97.5	0.811 (0.139)	8.831
		Site 2	87.5	0.414 (0.046)	
		Site 3	60	0.203 (0.107)	
Test 3	11/06/97	Site 1 (Control)	97.5	0.935 (0.152)	6.592
		Site 3	62.5	0.321 (0.173)	
Test 4	12/07/97	Site 1 (Control)	97.5	0.978 (0.037)	N.S.
		Site 2	100	0.907 (0.048)	
		Site 3	82.5	0.192 (0.103)	

Note: The T- values represented are those generated by Bonferroni *t*-test or Dunnett multiple comparisons between the control and treatment sediments. N.S. = No significant difference ($P = 0.05$).

four tests were conducted and a minimum of four replicates per site was used. All tests were conducted in constant temperature cabinets and maintained at $21 \pm 1^\circ\text{C}$ with a 16:8 L:D photoperiod.

Emergence test

Tests were conducted at $25 \pm 1^\circ\text{C}$ and a standard photoperiod of 16:8 L:D. The higher temperature (compared to growth tests) decreased test time and increased the efficiency of the test without altering toxicity effects (unpublished data). Illumination was supplied by overhead fluorescent lights (2 x Phillips 6F TL 36W/33 cool white fluorescent tubes) 700 mm above the test chambers. An average light intensity of 509 lux was maintained.

Test chambers were 1 L glass beakers (Pyrex low form glass beakers with spout: internal diameter 10 cm; 78.54 cm² area) with gauze screens to capture emergent adults. Each chamber contained 100 ml of sediment and 400 ml of overlying water (reconstituted freshwater; USEPA 1989). Beakers were gently aerated and the overlying water (90%) renewed daily (Test 1 & 2) so as to maintain water quality. This was later changed to every second day (Test 3) as it was noted that water chemistry did not vary greatly over 2 to 4 days. Water chemistry parameters (dissolved oxygen, temperature, pH and conductivity) were monitored using a TPS 90FL Microprocessor Field Analyser water quality meter. Ammonia (measured as ppm Ammonia Nitrogen) was measured using a LaMotte Ammonia Nitrogen in water test kit (LaMotte, PO Box 329 Chesterton, MD; Model Pan Code 4795). Larvae were fed 3 ml of a 9.14 g/L Wardleys[®] fish food suspension every second day.

A total of three emergence tests were conducted. Four replicates per treatment, each containing ten second instar larvae (Test 1) were used to start a test. This was increased to 30 larvae per chamber (Tests 2 - 3), the maximum larval load supportable, to lower test variability and increase the chance of detecting a difference between control and test treatments.

Larval load was calculated based on observations by Suedel and Rodgers (1994) that *C. tentans* larvae require a minimum food foraging area approximately equal to their body length.

Chambers were monitored twice daily for emergence until 10 days after the last recorded emergence for a given treatment. Emergence time was scored in days following first emergence (i.e. the first chironomid to emerge during a test was scored as day 0 and any subsequent emergence sequentially numbered). Newly emerged adults were collected with an aspirator, transferred to sample vials and killed by freezing. Adults found dead on the water surface were also classed as emerged if they were fully eclosed (i.e. no remnants of the pupal case associated with the carcass and no visible malformities) and were collected for subsequent weighing. Malformed emergents (< 0.1% of total emerged) were not scored and were treated as non-emergents in the data analysis.

At the completion of the test, adults collected from each chamber were sexed and the ratio of males to females determined. Males were easily identified from their plumose antennae and externally visible genitalia. Males and females from each chamber were then placed on separate pre-weighed plastic weighing boats and dried at 60°C for 24 hours so as to determine the average dry weight of males and females.

Statistical analysis

Data were assessed for normality and homogeneity of variance using the Shapiro-Wilk and Bartlett tests respectively. Following acceptance of normality, emergence data for the different treatments were assessed by one-way ANOVA followed by a one-tailed Dunnett's test for multiple comparisons. Mean dry weights of adults were also compared using one-way analysis of variance (ANOVA) followed by Dunnett's tests for multiple comparisons among treatments.

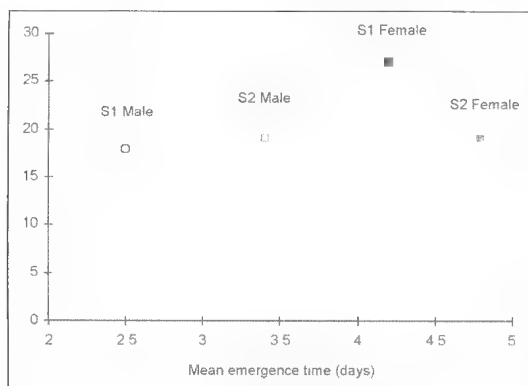


Fig. 1 Test 1: Mean emergence time of adult *C. maddeni* reared on Site 1 (S1) and Site 2 (S2) sediment with respect to sex. Open symbol = males, solid symbol = females.

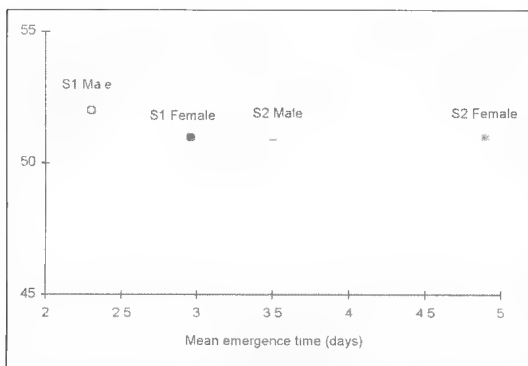


Fig. 2 Test 2: Mean emergence time of adult *C. maddeni* reared on Site 1 (S1) and Site 2 (S2) sediment with respect to sex. Open symbol = males, solid symbol = females.

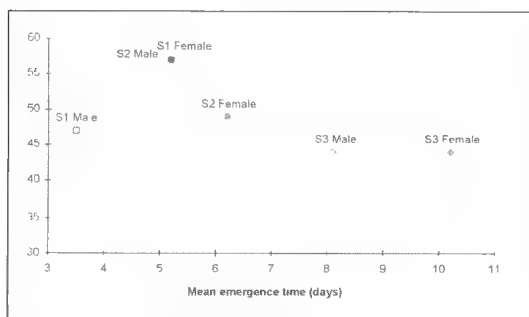


Fig. 3 Test 3: Mean emergence time of adult *C. maddeni* reared on Site 1 (S1), Site 2 (S2) and Site 3 (S3) sediment with respect to sex. Open symbol = males, solid symbol = females.

It should be pointed out that although the number of replicates was only four for each site, the sample size was in fact greater (at least 10 and up to 30) as both the emergence time and weight of individual adults can be treated as distinct data points.

Results

Growth tests

The comparative growth, expressed as mean dry weight, of larvae exposed to sediment from the three sites within the wetlands is shown in Table 1. The results (ANOVA) indicate that the different sediments tested produced a significant inhibition ($P = 0.05$) of growth in the larvae compared to the control (Test 1: $F_{\text{calc.}} = 15.981$, $\nu = 3$, 10; Test 2: $F_{\text{calc.}} = 24.69$, $\nu = 5$, 16; Test 3: $F_{\text{calc.}} = 23.759$, $\nu = 4$, 14; Test 4: $F_{\text{calc.}} = 77.388$, $\nu = 6$, 20). Multiple comparisons revealed that both Site 2 and Site 3 sediments were responsible for this effect in Tests 1 and 2. However, in Test 4 only sediment from Site 3 caused this effect.

Emergence tests

The adult emergence data shows a typical bimodal emergence pattern in all three tests conducted (Figures 1–3), with peaks in male emergence preceding female emergence peaks. Emergence of both males and females from the polluted sediments however was delayed compared to that from control sediments.

Statistical analysis (ANOVA) of the mean emergence times (Table 2) confirms the trends suggested in figures 1 to 3, with male, female and total number of emergents significantly delayed in the polluted sediments ($P = 0.05$) in Tests 2 and 3 (Test 2: $F_{\text{calc.}}(\text{total}) = 35.496$, $\nu = 1$, 6, $F_{\text{calc.}}(\text{male}) = 17.451$, $\nu = 1$, 6, $F_{\text{calc.}}(\text{female}) = 51.155$, $\nu = 1$, 6; Test 3: $F_{\text{calc.}}(\text{total}) = 76.761$, $\nu = 2$, 9, $F_{\text{calc.}}(\text{male}) = 23.279$, $\nu = 2$, 9, $F_{\text{calc.}}(\text{female}) = 68.799$, $\nu = 2$, 9). Multiple comparisons indicate that both Site 2 and Site 3 sediment are responsible for this response in Test 2. In Test 3, however, only female and total adult emergence times are significantly delayed in organisms exposed to both contaminated sediments. Male emergence was significantly delayed in organisms exposed to Site 3 sediment but not Site 2 sediment. No significant difference in emergence time for all adults, males only, or females only was achieved in Test 1. Due to the sample size being small ($n = 10$; i.e. ten larvae per replicate) the power of the test to detect a difference was severely limited, being less than 30%, approximately 35% and less than 30% respectively in test 1.

The comparative growth, expressed as mean dry weight, of emergent adults is shown in Table 3. A

TABLE 2. *Summary of mean adult emergence data from two contaminated sediments as compared with a control sediment from the Barker Inlet Wetland.*

Test Number	Date	Sediment Type	Number of Adults Emerged (% Emergence)	Mean Emergence Time (Days)* S. D. shown in parentheses	T- Value (1-tailed)
Test 1	21/05/97	Site1 (Control) – All Adults	45 (100)	3.547 (0.475)	
		Site 1 (Control) Males Only	18	2.511 (0.657)	
		Site 1 (Control) Females Only	27	4.200 (0.622)	
		Site 2 – All Adults	38 (95.0)	4.074 (0.489)	N.S.
		Site 2 – Male only	19	3.400 (0.559)	N.S.
		Site 2 – Female only	19	4.763 (0.354)	N.S.
Test 2	10 07/97	Site 1 (Control) – All Adults	103 (85.8)	2.618 (0.167)	
		Site 1 (Control) – Males Only	52	2.330 (0.331)	
		Site 1 (Control) – Females Only	51	2.955 (0.227)	
		Site 2 – All Adults	102 (85.0)	4.153 (0.488)	5.958
		Site 2 – Male only	51	3.536 (0.473)	4.177
		Site 2 – Female only	51	4.860 (0.482)	7.152
Test 3	9/08/97	Site 1 (Control) – All Adults	104 (86.7)	4.417 (0.343)	
		Site 1 (Control) – Males Only	47	3.473 (0.239)	
		Site 1 (Control) – Females Only	57	5.198 (0.618)	
		Site 2 – All Adults	115 (95.8)	5.399 (0.614)	2.398
		Site 2 – Males Only	56	4.518 (0.715)	N.S.
		Site 2 – Females Only	49	6.215 (0.689)	2.254
		Site 3 – All Adults	88	9.218 (0.715)	11.727
		Site 3 – Males Only	44	8.057 (1.55)	6.510
		Site 3 – Females	44	10.203 (0.604)	11.096

*Note: Emergence time is in days following first emergence (i.e. the first chironomid to emerge during a test was scored as day 0 and any subsequent emergence sequentially numbered). The T- values represented are those generated by Dunnett's multiple comparison between the control and treatment sediments. N.S. = No significant difference ($P = 0.05$).

TABLE 3. *Mean adult dry weight of midges exposed to contaminated and reference sediment from the Barker Inlet Wetland.*

Test Number	Sediment Type	% Recovery	Mean adult dry weight (mg) S. D. shown in parentheses	T- Value (1-tailed)
Test 1	Site 1 (Control) – All Adults	100	0.772 (0.027)	
	Site 1 (Control) – Males Only		0.528 (0.023)	
	Site 1 (Control) – Females Only		1.016 (0.038)	
	Site 2– All Adults	95	0.758 (0.016)	N.S.
	Site 2– Males Only		0.513 (0.050)	N.S.
	Site 2– Females Only		1.004 (0.022)	N.S.
Test 2	Site 1 (Control) – All Adults	85.8	0.708 (0.011)	
	Site 1 (Control) – Males Only		0.486 (0.044)	
	Site 1 (Control) – Females Only		0.929 (0.035)	
	Site 2– All Adults	42.5	0.620 (0.047)	3.655
	Site 2– Males Only		0.457 (0.052)	N.S.
	Site 2– Females Only		0.784 (0.049)	4.864
Test 3	Site 1 (Control) – All Adults	86.6	0.744 (0.021)	
	Site 1 (Control) – Males Only		0.504 (0.015)	
	Site 1 (Control) – Females Only		0.984 (0.044)	
	Site 2 – All Adults	95.8	0.620 (0.046)	3.901
	Site 2 – Males Only		0.476 (0.031)	N.S.
	Site 2 – Females Only		0.764 (0.108)	3.281
	Site 3 – All Adults	73.3	0.536 (0.059)	6.542
	Site 3 – Males Only		0.404 (0.031)	5.270
	Site 3 – Females		0.668 (0.116)	4.709

Note: The T- values represented are those generated by Dunnett's multiple comparison between the control and treatment sediments. N.S. = No significant difference ($P = 0.05$).

decrease in adult weight clearly corresponds to delayed emergence from polluted sediments, with average weight (irrespective of sex) and female weight significantly reduced in organisms exposed to Site 2 and Site 3 sediment (Tests 2 and 3) (Test 2: $F_{\text{calc}}(\text{total}) = 13.362$, $\nu = 1, 6$; $F_{\text{calc}}(\text{female}) = 23.656$, $\nu = 1, 6$; Test 3: $F_{\text{calc}}(\text{total}) = 21.665$, $\nu = 2, 9$; $F_{\text{calc}}(\text{female}) = 11.658$, $\nu = 2, 9$). Male weight was not significantly reduced in organisms reared in Site 2 sediment but was reduced in those exposed to Site 3 sediment in Test 3 (Test 2: $F_{\text{calc}}(\text{male}) = 0.755$, $\nu = 1, 6$; Test 3: $F_{\text{calc}}(\text{male}) = 14.804$, $\nu = 2, 9$).

Discussion

A review of the literature on the relationship between growth and emergence of chironomids (Maccek *et al.* 1976, Giesy *et al.* 1988, Pascoe *et al.* 1989, Taylor *et al.* 1991, Maund *et al.* 1992) supports the sensitivity of growth and emergence as test endpoints and agrees with the data presented here. The contaminated sediments which produced a reduction in larval weight in the growth experiments, also resulted in a retardation of adult emergence (Tests 2 and 3) emphasising the comparative sensitivity of the two response criteria. Comparison of emergence Test 2 and growth Test 4, both of which were conducted using aliquots of the same sediment samples, indicate that the end-point of emergence time may in fact be more sensitive to toxic effects than larval growth. A significant difference in male, female and total adult emergence time was observed in organisms reared on Site 2 sediment although no difference in larval growth was detected.

Significant delays in total and female emergence time were also observed for organisms exposed to Site 2 and 3 sediment in Test 3. Male emergence time, however, was only delayed following exposure to Site 3 sediment. This together with the growth data (Table 1) could be interpreted as indicating that Site 3 sediment was more toxic than Site 2 sediment. Adult numbers were also significantly lower following exposure to Site 3 sediment than to the control, whilst percentage emergence was almost identical for Site 2 and control treatments.

Test 1 did not result in significant delays in emergence time for contaminated compared to control sediments. This is most likely due to the low power of the test (approximately 30%). The low power was attributed to a small sample size ($n = 10$). Ten larvae were initially used following concerns of larval loading factors. A reduction in productivity of the stock cultures at this stage of the project (mid-late May) also meant the number of larvae available to start the test was limiting.

The fact that emergence time is delayed and adult survival significantly lowered (exposure to Site 3 sediment) in comparison to the control demonstrates that contaminated sediments exerted an inhibitory effect on larval survival and development and/or pupation – the larvae may tolerate the pollutant stress, with mortality occurring at the pupal stage, a period of substantial morphological and genetic change prior to adult emergence (Watts & Pascoe 1996). Although the exact nature of the toxic effect cannot be identified from these experiments, the delay in emergence time and reduction in total numbers is most likely due to larval effects as only a small proportion of malformed and dead pupae were recovered from the test chambers ($< 0.1\%$ of total emerged).

Adult dry weight also appears to correlate well with rearing on contaminated sediments, with average weight (irrespective of sex) and female weight significantly reduced in organisms exposed to both Site 2 and Site 3 sediment. Male dry weight was not significantly altered. This suggests that female growth is more sensitive to toxicant stress than male growth, which is not surprising when energy requirements and allocations are taken into consideration. The decrease in adult weight most likely corresponds to a reduction in fat stores which are generally higher in females. Females expend a considerable amount of energy in mate selection, egg production and oviposition site selection and, as such, require larger energy stores than males. Though feeding may occur in adult midges (Armitage 1995) this constitutes a small proportion of energy acquisition and does not contribute to reproductive output (Tokeshi 1995). Adults therefore rely almost entirely upon the energy stored during the larval (feeding) stage to accomplish reproduction. Thus, the larval stage is extremely important to the success of the adult female. The increased cost of pollution tolerance during the larval stage means more energy is required for survival and development, hence less energy is available for storage. Significant reductions in weight (fat storage) may affect mating success and lead to a reduction in genetic fitness of the population as a whole and, at worst, local extinction of the species.

Aside from the sensitivity of emergence as an endpoint, the fact that increased emergence time corresponds to rearing on polluted sediments is logistically useful. The time saved by not having to recover larvae (by sieving) at the end of a test reduces labour intensity and hence cost associated with bulk sediment assays. Error associated with larval recovery, particularly if substantial growth impairment has occurred, is also overcome and the simplicity of the test is greatly increased, requiring

only daily monitoring of the test chambers.

We believe that with further technical development, the chironomid emergence test could become a standard procedure to assess the toxicity of contaminated sediments in Australia. Not only is the emergence endpoint more convenient and more sensitive than larval growth endpoints, but it is also more biologically realistic because it integrates toxic effects on chironomid life history giving an indication

of impacts on the reproductive stage of the adult.

Acknowledgments

We acknowledge the assistance and advice of Joe Bidwell, Chris Madden, John Gorrie and Clive Jenkins. Financial support was provided in part by the Multifunction Polis Development Corporation and The University of South Australia.

References

- ARMITAGE, P. D. (1995) Behaviour and ecology of adults pp. 194-224 *In* Armitage, P.D., Cranston, P.S. & Pinder, L.C.V. (Eds.) "The Chironomidae, the biology and ecology of non-biting midges" (Chapman & Hall, London).
- ASTM (1993) Standard guide for conducting sediment toxicity tests with freshwater invertebrates. E 1383-93. *In* Annual book of ASTM Standards, Vol. 11.04. American Society for Testing and Materials, Philadelphia, PA, USA.
- BROWN, V. M. (1993) Concepts and realities in toxicity testing for the protection of aquatic environments from wastes. *Aust. Biol.* **6**, 133-141.
- CHAPMAN, P. M. (1995) Bioassay testing for Australia as part of water quality assessment programmes. *Aust. J. Ecol.* **20**, 7-19.
- GIESY, J. P., GRANEY, R. L., NEWSTED, J. L., ROSIU, C. J., BENDA, A., KREIS, R. G. & HOVARTH, F. J. (1988) Comparison of three sediment bioassay methods using Detroit River sediments, *Environ. Toxicol. Chem.* **7**, 483-498.
- JENKINS, C., MULCAHY, D., & ARGUE, J. (1997) Heavy metals in the sediments of the Barker Inlet Wetland: Baseline Survey, Unpublished Report, Urban Water Resources Centre, University of South Australia.
- LIBER, K., CALL, D., DAWSON, T., WHITEMAN, F. & DILLION, T. (1996) Effects of *Chironomus tentans* larval growth retardation on adult emergence and ovipositing success: implications for interpreting freshwater sediment bioassays. *Hydrobiologia* **323**, 155-167.
- MAECK, K., BUXTON, K., DERR, S., DEAN, J. & SAUNTER, S. (1976) Chronic toxicity of lindane to selected aquatic invertebrates and fishes. *U. S. Environmental Protection Agency Eco. Res. Ser.* EPA 600/3-76-046.
- MAUND, S. J., PEITHER, A., TAYLOR, E. J., JÜTTNER, I., BEYERLE-PFNÜR, R., LAY, J. P. & PASCOE, D. (1992) Toxicity of lindane to freshwater insect larvae in compartments of an experimental pond. *Ecotoxicol. Environ. Safety* **23**, 76-88.
- NORRIS, R. H. & NORRIS, K. R. (1995) The need for biological assessment of water quality: Australian perspective. *Aust. J. Ecol.* **20**, 1-6.
- PASCOE, D., WILLIAMS, K. A. & GREEN, D. W. J. (1989) Chronic toxicity of cadmium to *Chironomus riparius* Meigen - effects upon larval development and adult emergence. *Hydrobiologia* **175**, 109-115.
- SMITH, B., KOKKINN, M. & BIDWELL, B. (1999) A toxicity test for contaminated Australian freshwater sediments using the larvae of *Chironomus maddeni* (Diptera: Chironomidae), a species native to South Australia. *Aust. J. Ecotox.* **5**, 11-20.
- SUEDEL, B. C. & RODGERS, J. J. (1994) Responses of *Hyallella azteca* and *Chironomus tentans* to particle size distribution and organic matter content of formulated and natural freshwater sediments. *Environ. Toxicol. Chem.* **13**, 1639-1648.
- TAYLOR, E. J., MAUND, S. J. & PASCOE, D. (1991) Evaluation of a chronic toxicity test using growth of the insect *Chironomus riparius* Meigen pp. 343-352 *In* Jeffrey, D.W. & Madden, B. (Eds.) "Bioindicators and Environmental Management, Proc. 6th IUBS Symposium, Dublin, 1990" (Academic Press Limited, London).
- TOKESHI, M. (1995) Life cycles and population dynamics pp. 225-268 *In* Armitage, P.D., Cranston, P.S. & Pinder, L.C.V. (Eds.) "The Chironomidae, the biology and ecology of non-biting midges" (Chapman & Hall, London).
- USEPA (1989) Section 7 Dilution Water pp. 24-26 *In* Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms 2nd ed. EPA/600/4-89/001. Office of Research and Development, Cincinnati, Ohio.
- USEPA (1994) "Methods for Measuring the Toxicity and Bioaccumulation of Sediment-associated Contaminants with Freshwater Invertebrates" EPA/600/R-94/024. Office of Research and Development, Duluth, Minnesota.
- WATTS, M. & PASCOE, D. (1996) Use of the freshwater macroinvertebrate *Chironomus riparius* (Diptera; Chironomidae) in the assessment of sediment toxicity. *Water Sci. Technol.* **34**(7/8), 101-107.
- WENTSEL, R., MCINTOSH, A. & MCCAFFERTY, W. P. (1978) Emergence of the midge *Chironomus tentans* when exposed to heavy metal contaminated sediment. *Hydrobiologia* **57**, 195-196.

**SPATIAL AND TEMPORAL DISTRIBUTION OF CULEX
AUSTRALICUS DOBROTWORSKY AND DRUMMOND AND
CULEX GLOBOCOXITUS DOBROTWORSKY (DIPTERA:
CULICIDAE) AT THE GIPPSLAND LAKES
IN EASTERN VICTORIA**

BY P. S. BARTON¹, J. G. ABERTON¹ & E. WISHART²

Summary

Barton, P. S., Aberton, J. G. & Wishart, E. (2004) Spatial and temporal distribution of *Culex australicus* Dobrotworsky and Drummond and *Culex globocoxitus* Dobrotworsky (Diptera: Culicidae) at the Gippsland Lakes in eastern Victoria. Trans. R. Soc. S. Aust. 128(2), 219-223, 30 November, 2004.

This paper re-examines previously published data on general mosquito numbers from the Gippsland Lakes, plus additional data collected since that time, and provides greater spatial and temporal definition specifically for populations of *Culex australicus* Dobrotworsky and Drummond and *Culex globocoxitus* Dobrotworsky. A total of 6,843 *Cx. australicus* and 45,691 *Cx. globocoxitus* were collected over 1188 trap-nights from seven trap sites during trapping seasons from 1999-2001.

Key Words: *Culex australicus*, *Culex globocoxitus*, Culicidae, Gippsland Lakes.

SPATIAL AND TEMPORAL DISTRIBUTION OF *CULEX AUSTRALICUS*
DOBROTORSKY AND DRUMMOND AND *CULEX GLOBOCOXITUS*
DOBROTORSKY (DIPTERA: CULICIDAE) AT THE GIPPSLAND LAKES
IN EASTERN VICTORIA

by P. S. BARTON¹, J. G. ABERTON¹ & E. WISHART²

Summary

BARTON, P. S., ABERTON, J. G. & WISHART, E. (2004) Spatial and temporal distribution of *Culex australicus* Dobrotworsky and Drummond and *Culex globocoxitus* Dobrotworsky (Diptera: Culicidae) at the Gippsland Lakes in eastern Victoria. *Trans. R. Soc. S. Aust.* 128(2), 219–223, 30 November, 2004.

This paper re-examines previously published data on general mosquito numbers from the Gippsland Lakes, plus additional data collected since that time, and provides greater spatial and temporal definition specifically for populations of *Culex australicus* Dobrotworsky and Drummond and *Culex globocoxitus* Dobrotworsky. A total of 6,843 *Cx. australicus* and 45,691 *Cx. globocoxitus* were collected over 1188 trap-nights from seven trap sites during trapping seasons from 1990–2001. Composition ranged from 0.2 – 22.5% and 0.6 – 39.7% of the total trap catch, for *Cx. australicus* and *Cx. globocoxitus* respectively, across all trap sites. McLennan Strait, Marlay Point and Matheson Swamp trap sites had higher mean abundances of *Cx. australicus* and *Cx. globocoxitus* relative to other trap sites, and peak densities were observed during December or January. Some variation in numbers was accounted for by lagged rainfall and temperature.

KEY WORDS: *Culex australicus*, *Culex globocoxitus*, Culicidae, Gippsland Lakes.

Introduction

The mosquito fauna of the Gippsland Lakes region of eastern Victoria is of interest due to its potential role in the transmission of enzootic Ross River (RR) and Barmah Forest (BF) viruses to humans (Campbell *et al.* 1989; Aldred *et al.* 1990). The dominant mosquito species in the region, and the main vector of RR virus, is the southern saltmarsh mosquito *Ochlerotatus camptorhynchus* (Thomson) (Dhileepan *et al.* 1997; Wishart *et al.* 2001, 2002). This mosquito species inhabits the large areas of brackish wetlands associated with the area. Other common species in the Gippsland lakes region include *Culex australicus* Dobrotworsky and Drummond and *Culex globocoxitus* Dobrotworsky (Wishart *et al.* 2001; Barton *et al.* 2004). These less abundant species probably play a role in the ecology of RR or BF in the region, but have thus far received very little attention from an ecological standpoint. Isolations of RR have been from both *Cx. australicus* and *Cx. globocoxitus* in the Gippsland region (Azoulas *et al.* 2003), and this highlights the need for further work on these species.

Early observations on the seasonal population characteristics of mosquitoes from Gippsland were made by Dobrotworsky (1965), with further detail produced by Dhileepan *et al.* (1997) in their survey of mosquitoes along the eastern coast of Victoria.

The large wetlands associated with the Gippsland Lakes, and the occurrence of arboviral disease in the region, have led to the need for further delineation of the mosquito fauna in this area.

In this current paper, we examine mosquito surveillance data by trap location from two local government shires covering the Gippsland Lakes in eastern Victoria. We also provide a longitudinal extension of some of the data covered by Dhileepan *et al.* (1997) with improved re-analysis aimed towards greater spatial and temporal definition of the mosquito species *Cx. australicus* and *Cx. globocoxitus* to provide a better understanding of their potential role in arboviral ecology, and for use towards mosquito control.

Methods

The Gippsland Lakes are a group of coastal lagoons in southeastern Victoria about 200 km east of Melbourne (Fig. 1) (Webster *et al.* 2001). The lake system consists of three main water bodies including Lake Wellington (138 sq km; shoreline 60 km), Lake Victoria (110 sq km; shoreline 100 km) and Lake King (92 sq km; shoreline 160 km). In addition to these lakes there are a number of smaller lagoons associated with extensive swamps on a low-lying depositional coastal plain (Bird 1978).

Coordinated mosquito monitoring occurred in East Gippsland Shire (formerly Shire of Bairnsdale) (147° 35' E, 37° 50' S) during May to March 1990–1991, November to March 1991–1994, and November 1994, and also in Wellington Shire

¹ School of Ecology and Environment, Deakin University, Geelong VIC 3217;

² Victorian Institute of Animal Science, 475 Mickleham Road, Attwood VIC 3049

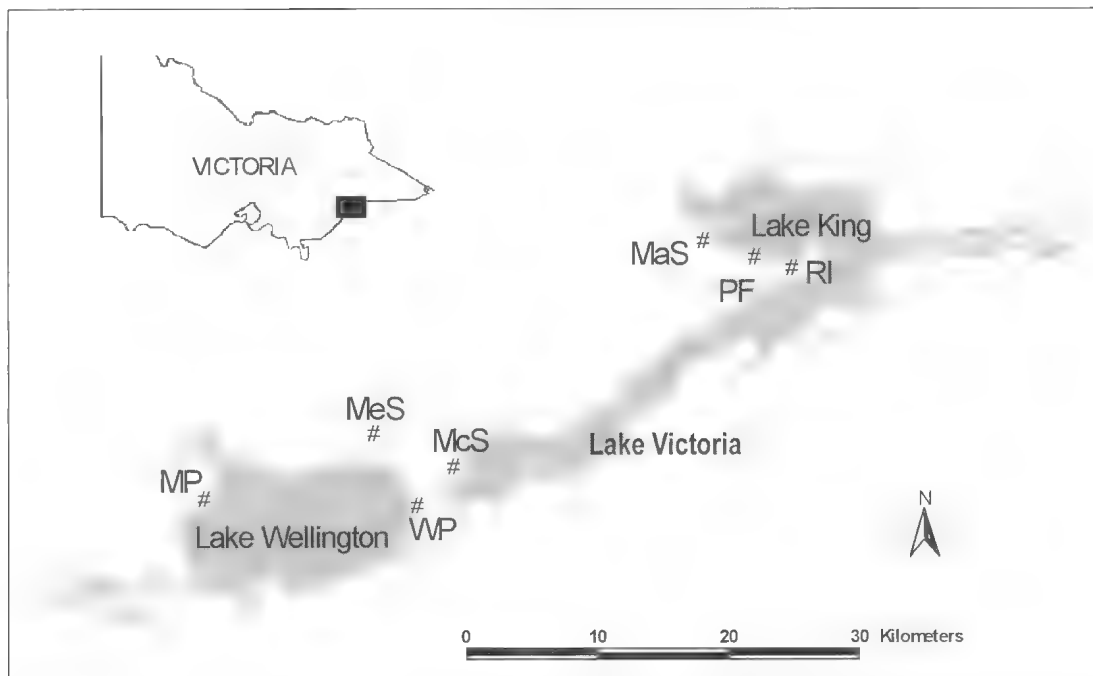


Fig. 1. Location of trap sites at the Gippsland Lakes in eastern Victoria. MP = Marlay Point, MeS = Meerlieu School, WP = Wood Pile Rd, McS = McLennan Strait, MaS = Matheson Swamp, PF = Point Fullarton, RI = Raymond Island.

(formerly Shire of Avon) ($147^{\circ} 04' E$, $38^{\circ} 07' S$) during November–April 1991–2000 and October–April 2000–2001, using CO_2 baited encephalitis-vector-surveillance (EVS) light-traps. Data used in this study came from three trap sites maintained near Lake King and four trap sites near Lake Wellington (Fig. 1). Mosquitoes were identified by the Environmental Health Officer from each shire, or at the Victorian Institute of Animal Science, Attwood, by the resident entomologist in the Arbovirology Unit. Meteorological data used in this study were sourced from the Bureau of Meteorology for Bairnsdale and East Sale, for the periods 1990–1994 and 1991–2001 respectively.

Seasonal trap capture details of *Cx. australicus*, *Cx. globocoxitus* and total mosquito captures were tabulated for each trap locality. A 2-Way Analysis of Variance with Student-Newman-Keuls post-hoc tests (SPSS v11.5) was used to test for significant differences in mean mosquito abundance between the trap localities and monthly trap captures. Relationships between the meteorological factors minimum temperature, maximum temperature, mean temperature and total rainfall, and mosquito abundance at each trap site were analysed using linear regression methods. Monthly rainfall data were lagged one and two months. All mosquito abundance data were $\log(x + 1)$ transformed prior to statistical

analysis. For East Gippsland Shire the months May to October of 1990 were excluded from the ANOVA due to only one sampling. For Wellington Shire the month of October 2000 was excluded from the ANOVA due to only one sampling. All months were used in the regression analysis.

Results

A total of 6,843 *Cx. australicus* and 45,691 *Cx. globocoxitus* were collected over 1188 trap-nights from seven trap sites during trapping seasons from 1990–2001. For *Cx. australicus*, percent composition ranged from 0.2% at Wood Pile Rd to 22.5% at Matheson Swamp. For *Cx. globocoxitus*, composition ranged from 0.6% at Raymond Island to 39.4% at Marlay Point and 39.7% at Matheson Swamp.

Salinity recordings obtained from each trap site were 35 ppt for Wood Pile Rd, 6 ppt for Marlay Point, 18 ppt at McLennan Strait, 38 ppt at Raymond Island and 37 ppt at Point Fullarton. No salinity readings were obtained from Meerlieu School or Matheson Swamp. Vegetation at all sites was dominated by *Sarcocornia quinqueflora* (Beaded Glasswort), *Juncus kraussii* (Sea Rush), *Carpobrotus rossii* (Pigface) and *Arthrocnemum arbusculum* (Shrubby Glasswort), except for Marlay Point and

Matheson Swamp, which was dominated by *Sporobolus virginicus* (Salt Couch) and *Phragmites australis* (Common Reed) respectively. No noteworthy larval habitat was noted at Meerlieu School.

Significant differences in mean *Cx. australicus* numbers were found between trap locations for both Wellington (d.f. = 5, M.S. = 2.307, F = 11.477, P < 0.001) and East Gippsland Shires (d.f. = 4, M.S. = 0.619, F = 3.824, P < 0.05). The sites of highest production of *Cx. australicus* were identified as Marlay Point and Matheson Swamp (Table 1). Significant differences in mean *Cx. globocoxitus* numbers were found between trap locations for both Wellington (d.f. = 5, M.S. = 4.148, F = 11.307, P < 0.001) and East Gippsland Shires (d.f. = 4, M.S. = 0.605, F = 2.637, P < 0.001). Sites of highest production of *Cx. globocoxitus* were identified as

McLennan Strait and Marlay Point.

Significant differences in mean *Cx. australicus* numbers were obtained for month of trapping for both Wellington (d.f. = 3, M.S. = 2.245, F = 11.167, P < 0.001) and East Gippsland Shires (d.f. = 2, M.S. = 1.917, F = 11.819, P < 0.001). Significant differences in mean *Cx. globocoxitus* numbers were obtained for month of trapping for both Wellington (d.f. = 3, M.S. = 11.394, F = 31.056, P < 0.001) and East Gippsland Shires (d.f. = 2, M.S. = 1.785, F = 7.788, P < 0.01). No significant interaction was obtained between trap locality and month of trapping for *Cx. globocoxitus*. Months of peak density of both mosquito species for both Wellington and East Gippsland shires were December or January (Table 1).

Statistically significant predictions of mosquito abundance using one or two meteorological factors

TABLE 1. Trap sites and month of trapping ranked in order of mean abundance for *Cx. australicus* and *Cx. globocoxitus* from Wellington and East Gippsland Shires.

	Wellington Shire				East Gippsland Shire			
	Trap site	Mean \pm SE	Month	Mean \pm SE	Trap site	Mean \pm SE	Month	Mean \pm SE
<i>Culex australicus</i>	Marlay Point	12.3 \pm 3.0	December	13.1 \pm 3.5	Matheson Swamp	15.5 \pm 5.3	January	12.5 \pm 5.6
	McLennan Strait	6.8 \pm 2.0	January	9.3 \pm 3.0	Point Fullarton	4.0 \pm 1.7	December	11.9 \pm 6.1
	Meerlieu School	2.3 \pm 0.8	February	6.6 \pm 3.0	Raymond Island	2.1 \pm 0.7	November	5.0 \pm 1.8
	Wood Pile Rd	2.1 \pm 0.8	November	5.3 \pm 1.5			February	4.0 \pm 1.5
			March	0.9 \pm 0.2			March	2.1 \pm 0.8
			April	0.1 \pm 0.1				
<i>Culex globocoxitus</i>	McLennan Strait	103.9 \pm 52.8	January	136.1 \pm 78.3	Matheson Swamp	27.7 \pm 12.7	January	23.1 \pm 16.0
	Marlay Point	62.7 \pm 10.7	December	54.2 \pm 15.5	Point Fullarton	3.6 \pm 0.9	December	13.0 \pm 8.8
	Wood Pile Rd	10.7 \pm 2.7	February	42.0 \pm 10.8	Raymond Island	2.6 \pm 1.2	February	11.0 \pm 7.8
	Meerlieu School	5.0 \pm 1.3	March	24.9 \pm 7.1			March	4.4 \pm 1.7
			November	13.9 \pm 3.2			November	1.5 \pm 0.7
			April	2.5 \pm 0.7				

TABLE 2. Summary of linear regression results for mean monthly numbers of *Cx. australicus* and *Cx. globocoxitus* with meteorological factors at 7 trap sites at the Gippsland Lakes, Victoria.

<i>Culex australicus</i>			
Trap Locality	Equation	F	P
Wood Pile Rd	$\log(y+1) = -0.419 + (0.043 \times \text{min temp}) + (0.003 \times \text{rainfall})$	6.99	< 0.01
Marlay Point	$\log(y+1) = -0.744 + (0.096 \times \text{min temp}) + (0.006 \times \text{rainfall}+1)$	10.42	< 0.01
McLennan Strait	$\log(y+1) = -0.369 + (0.044 \times \text{min temp}) + (0.006 \times \text{rainfall}+1)$	5.42	< 0.01
Meerlieu School	$\log(y+1) = -0.347 + (0.037 \times \text{min temp}) + (0.003 \times \text{rainfall}+1)$	4.43	< 0.05
Raymond Island	$\log(y+1) = -0.579 + (0.042 \times \text{mean temp}) + (0.003 \times \text{rainfall}+1)$	4.09	< 0.05
Point Fullarton	$\log(y+1) = -0.313 + (0.060 \times \text{min temp}) + (0.002 \times \text{rainfall}+1)$	3.74	< 0.05
Matheson Swamp	$\log(y+1) = -0.775 + (0.054 \times \text{min temp})$	8.04	< 0.05
<i>Culex globocoxitus</i>			
Trap Locality [^]	Equation	F	P
Wood Pile Rd	$\log(y+1) = -0.702 + (0.094 \times \text{min temp}) + (0.006 \times \text{rainfall}+1)$	12.31	< 0.01
Marlay Point	$\log(y+1) = -0.383 + (0.125 \times \text{min temp}) + (0.007 \times \text{rainfall}+1)$	15.42	< 0.01
McLennan Strait	$\log(y+1) = -0.776 + (0.129 \times \text{min temp}) + (0.010 \times \text{rainfall}+1)$	13.91	< 0.01
Meerlieu School	$\log(y+1) = -0.317 + (0.059 \times \text{min temp}) + (0.003 \times \text{rainfall}+1)$	4.19	< 0.05
Point Fullarton	$\log(y+1) = -0.423 + (0.044 \times \text{mean temp}) + (0.003 \times \text{rainfall}+1)$	5.37	< 0.05
Matheson Swamp	$\log(y+1) = -1.073 + (0.178 \times \text{min temp})$	5.15	< 0.05

[^]No significant result obtained for Raymond Island

were achieved for both mosquito species at all sites except for numbers of *Cx. globocoxitus* at Raymond Island (Table 2). A linear combination of temperature and lagged rainfall successfully predicted the abundance of *Cx. australicus* and *Cx. globocoxitus* at all trap sites except Matheson Swamp, where temperature by itself was a successful predictor.

Discussion

In general, the low numbers of *Cx. australicus* and *Cx. globocoxitus* outlined in this study, relative to the dominance of the mosquito *Oc. camptorhynchus* outlined by Barton *et al.* (2004), are probably due to the saline nature of the available breeding sites. Larvae of *Cx. australicus* and *Cx. globocoxitus* are known to prefer fresh to brackish water (Dobrotworsky 1965). The relatively lower salinity levels recorded at Marlay Point and McLennan Strait, and indicated at Matheson Swamp by the presence of the freshwater common reed, may go some way towards explaining the higher abundance of *Cx. australicus* and *Cx. globocoxitus* at these sites, although the effects of seasonal salinity changes is unclear.

Marlay Point and Matheson Swamp were defined as the sites of greatest production of *Cx. australicus* in Wellington Shire and east Gippsland Shire respectively. Significant differences were found between monthly numbers of *Cx. australicus*, with peak numbers in *Cx. australicus* density during December and January. The trap sites at McLennan Strait (WS), Marlay Point (WS) and Matheson Swamp (EGS), were defined as sites of greatest *Cx. globocoxitus* production, with peaks in *Cx. globocoxitus* density occurring in January for both shires. From this analysis, it is noted that the average peak density of *Cx. australicus* and *Cx. globocoxitus* occurs one or two months later than the dominant mosquito species *Oc. camptorhynchus* (Barton *et al.* 2004). This difference in seasonal numbers may have implications for arbovirus ecology in the region, with these species possibly playing a role in seasonal virus amplification or maintenance in animal populations comparatively later than that suggested for the Murray Valley of northern Victoria (Russell 1993; Dhileepan 1996; Azoulas *et al.* 2003). It is unlikely that these species are directly involved in transmission since both *Culex* species prefer avian blood sources (Dobrotworsky 1965), but this hypothesis provides an avenue for further study.

The predominant successful prediction of mosquito numbers with rainfall lagged one month

suggest this time delay is important. It would appear that larger numbers of mosquitoes are produced one month after drainage from surrounding catchments inundates breeding habitat, allowing for the laying of eggs and facilitating adult emergence. This occurrence was also noted for *Oc. camptorhynchus* at these trap sites (Barton *et al.* 2004). Minimum temperature was also successful in predicting mosquito abundance at the majority of sites, for both mosquito species. It has been well documented that temperature is an important factor influencing mosquito activity (Clements 1992). It is likely that the activity of both *Cx. australicus* and *Cx. globocoxitus* is greater with warmer overnight temperatures, and this correlates with the peaking of numbers observed in December, January and February.

In conclusion, greater definition of numbers of *Cx. australicus* and *Cx. globocoxitus* at different trap sites has been achieved, with McLennan Strait, Marlay Point and Matheson Swamp identified as sites of highest production of these species. These sites should have a higher priority for further work given the goal of control of these species. Greater temporal definition of numbers of *Cx. australicus* and *Cx. globocoxitus* has also been achieved, with months of peak density identified as December or January. This contrasts with that of the dominant mosquito species and important RR vector in the region (Russell 2002), *Oc. camptorhynchus*, which appears to peak in November or December (Barton *et al.* 2004). This comparatively later peak in numbers for *Cx. australicus* and *Cx. globocoxitus* may be important in the ecology of RR or BF viruses, but this hypothesis remains to be tested with future virus surveys. This study highlights the usefulness of long-term mosquito monitoring in providing practical solutions to mosquito control issues, with the methods outlined in this paper relevant to mosquito control practices elsewhere in Australia.

Acknowledgements

Trapping of all mosquitoes during the periods 1990-1994 and 1991-2001, was carried out by East Gippsland and Wellington Shire councils respectively, and was funded by the Victorian Department of Human Services. John Roche provided the mosquito-monitoring data for East Gippsland Shire. This study was supported by a Deakin University Postgraduate Research Scholarship.

References

- ALDRED, J., CAMPBELL, J., DAVIS, G., LEHMANN, N. & WOLSTENHOLME, J. (1990). Barmah Forest virus in the Gippsland Lakes region, Victoria. *Medical Journal of Australia* **153**, 434.
- AZOULAS, J. K., WISHART, E., BIBBY, S. & AINSWORTH, C. (2003). Isolation of Ross River virus from mosquitoes and from horses with signs of musculo-skeletal disease. *Australian Veterinary Journal* **81**, 344-347.
- BARTON, P. S., ABERTON, J. G. & KAY, B. H. (2004). Spatial and temporal definition of *Ochlerotatus camptorhynchus* (Thomson) (Diptera: Culicidae) in the Gippsland Lakes of eastern Victoria. *Australian Journal of Entomology* **43**, 16-22.
- BIRD, E. C. F. (1978). "The geomorphology of the Gippsland Lakes region". (Ministry for Conservation, Victoria).
- CAMPBELL, J., ALDRED, J. & DAVIS, G. (1989). Some aspects of the natural history of Ross River virus in southeast Gippsland, Victoria. *Arbovirus Research in Australia* **5**, 24-28.
- CLEMENTS, A. N. (1992). "The biology of mosquitoes. Development, nutrition and reproduction". (Chapman & Hall, London).
- DHILEEPAN, K. (1996) Mosquito seasonality and arboviral disease incidence in Murray Valley, southeast Australia. *Medical and Veterinary Entomology* **10**, 375-384.
- _____, PETERS, C. & PORTER, A. (1997). Prevalence of *Aedes camptorhynchus* (Thomson) (Diptera: Culicidae) and other mosquitoes in the eastern coast of Victoria. *Australian Journal of Entomology* **36**, 183-190.
- DOBROTWORSKY, N. V. (1965). 'The mosquitoes of Victoria (Diptera: Culicidae)'. (Melbourne University Press, Melbourne).
- RUSSELL, R. C. (1993). "Mosquitoes and mosquito-borne disease in southeastern Australia. A guide to the biology, relation to disease, surveillance, control and the identification of mosquitoes in southeastern Australia". (Department of Medical Entomology, Westmead Hospital, Sydney).
- _____. (1995). Arboviruses and their vectors in Australia: an update on the ecology and epidemiology of some mosquito-borne arboviruses. *Review of Medical and Veterinary Entomology* **83**, 141-158.
- _____. (2002). Ross River virus: Ecology and Distribution. *Annual Review of Entomology* **47**, 1-31.
- WEBSTER, I. T., PARSLAW, J. S., GRAYSON, R. B., MOLLOY, R. P., ANDREWARTHA, J., SAKOV, P., SEONG, T. K., WALKER, S. J. & WALLACE, B. B. (2001). "Gippsland Lakes environmental study. Assessing options for improving water quality and ecological function". (CSIRO).
- WISHART, E., AZOULAS, J. K. & BROWN, K. (2001). "Victorian arbovirus disease control program. Mosquito monitoring report 2000/2001". (Victorian Institute of Animal Science, Attwood).
- _____, _____ & _____ (2002). "Victorian arbovirus disease control program. Mosquito monitoring report 2001/2002". (Victorian Institute of Animal Science, Attwood).

STUDIES OF TEMPORAL HOST-SEEKING PATTERNS OF CULEX ANNULIROSTRIS (DIPTERA: CULICIDAE): A COMPARISON OF METHODS AND POPULATIONS

By C. R. WILLIAMS†, A. E. SNELL‡ & M. J. KOKKINN**

Summary

Williams, C. R., Snell, A. E. & Kokkinn, M. J. (2004). Studies of temporal host-seeking patterns of *Culex Annulirostris* (Diptera: Culicidae): a comparison of methods and populations. *Trans. R. Soc. S. Aust.* 128(2), 225-229, 30 November, 2004.

The objectives of this study were to evaluate the use of hourly carbon-dioxide baited trapping as an alternative to human biting catch for determining the timing of mosquito biting behaviour, and to confirm that previously reported temporal host-seeking patterns for *Culex annulirostris* are valid across its geographic range.

Key Words: Culicidae, *Culex annulirostris*, host-seeking, carbon-dioxide, River Murray, northeast South Australia.

STUDIES OF TEMPORAL HOST-SEEKING PATTERNS OF *CULEX ANNULIROSTRIS* (DIPTERA: CULICIDAE): A COMPARISON OF METHODS AND POPULATIONS

by C. R. WILLIAMS^{*†}, A. E. SNELL[‡] & M. J. KOKKINN^{*}

Summary

WILLIAMS, C. R., SNELL, A. E. & KOKKINN, M. J. (2004) Studies of temporal host-seeking patterns of *Culex Annulirostris* (Diptera: Culicidae): a comparison of methods and populations. *Trans. R. Soc. S. Aust.* **128**(2), 225-229, 30 November, 2004.

The objectives of this study were to evaluate the use of hourly carbon-dioxide baited trapping as an alternative to human biting catch for determining the timing of mosquito biting behaviour, and to confirm that previously reported temporal host-seeking patterns for *Culex annulirostris* are valid across its geographic range.

Female *Cx. annulirostris* were captured hourly using concurrent human biting catch and carbon-dioxide baited trapping. This was performed in two regions of South Australia (SA): the northeast and the Upper River Murray regions, in January 2001. Significant correlations in hourly captures of *Cx. annulirostris* using the two methods were detected. Surprisingly, differences in temporal host-seeking activity patterns of this species were discovered between the two regions and differed partially from previously reported findings, indicating that the behaviour of this species is heterogeneous across its range.

Carbon-dioxide baited traps yield very similar temporal host-seeking patterns to human-biting catches, thereby providing an alternative sampling method. Carbon-dioxide baited traps may be used to study temporal biting patterns of mosquitoes in order to reduce the disease risk to investigators. Behavioural variations in widespread mosquito species (such as *Cx. annulirostris*) may have implications for the management of mosquito-borne diseases.

KEY WORDS: Culicidae, *Culex annulirostris*, host-seeking, carbon-dioxide, River Murray, northeast South Australia.

Introduction

Knowledge of temporal host-seeking patterns of mosquitoes is important for understanding mosquito-host contact, as mosquitoes will only bite hosts that are available during the period of their host-seeking activity. Most studies of these patterns have involved the collection of mosquitoes attracted to human bait at regular intervals throughout the diel (e.g. Mattingly 1949; Haddow & Ssenkubuge 1965; Charlwood & Wilkes 1979; Russell 1987a; Ludueña Almeida & Gorla 1995).

The use of human bait to sample mosquito populations is specific for determining the diversity and abundance of those of medical importance to humans. However, pathogens transmitted by mosquitoes (which include a range of parasitic protozoa and viruses) may represent a significant health risk to collectors. In addition, the use of human bait has limitations in sampling precision, with inconsistencies in the collection efficiency of different investigators, the variable attractiveness of

different humans (Khan 1977; Schreck *et al.* 1990; Lindsay *et al.* 1993; Knols *et al.* 1995), and the large human resource requirements for replicate data collection.

The use of carbon-dioxide baited traps to measure temporal host-seeking patterns (Mitchell 1982; Reisen *et al.* 1997) potentially overcomes these limitations and reduces the risk of contracting a mosquito-borne disease. Correlations between the total number of mosquitoes captured by carbon-dioxide baited traps in a day and human-biting catch have been demonstrated (Ludueña Almeida & Gorla 1995; Reisen *et al.* 1997; Lines *et al.* 1991; Davis *et al.* 1995; Vaidyanathan & Edman 1997). However, no correlations of hourly catch data for the two methods have been reported.

Culex annulirostris Skuse is widely distributed throughout Australia, New Guinea, the Moluccas and Lesser Sunda Islands, and parts of Micronesia (Lee *et al.* 1989). It is more common in rural settings as opposed to urban environments, and is considered a major vector of Ross River, Barmah Forest, Murray Valley encephalitis, Kunjin and Japanese encephalitis viruses (Russell 1995, 2002; Mackenzie *et al.* 1998). *Culex annulirostris* is generally crepuscular/nocturnal in its biting habits (Russell 1987a,b) and is strongly exophagic (Kay 1985). It will take blood from a wide variety of hosts (Kay *et al.* 1985).

The aim of this project was to compare the hourly

^{*} School of Pharmaceutical, Molecular and Biomedical Sciences, University of South Australia, North Terrace, Adelaide 5000, South Australia.

[†] Present address: School of Public Health & Tropical Medicine, James Cook University, PO Box 6811 Cairns 4870, Queensland. Email craig.williams1@jcu.edu.au
Department of Public Health, University of Otago, Wellington School of Medicine, PO Box 7343, Wellington South, New Zealand.

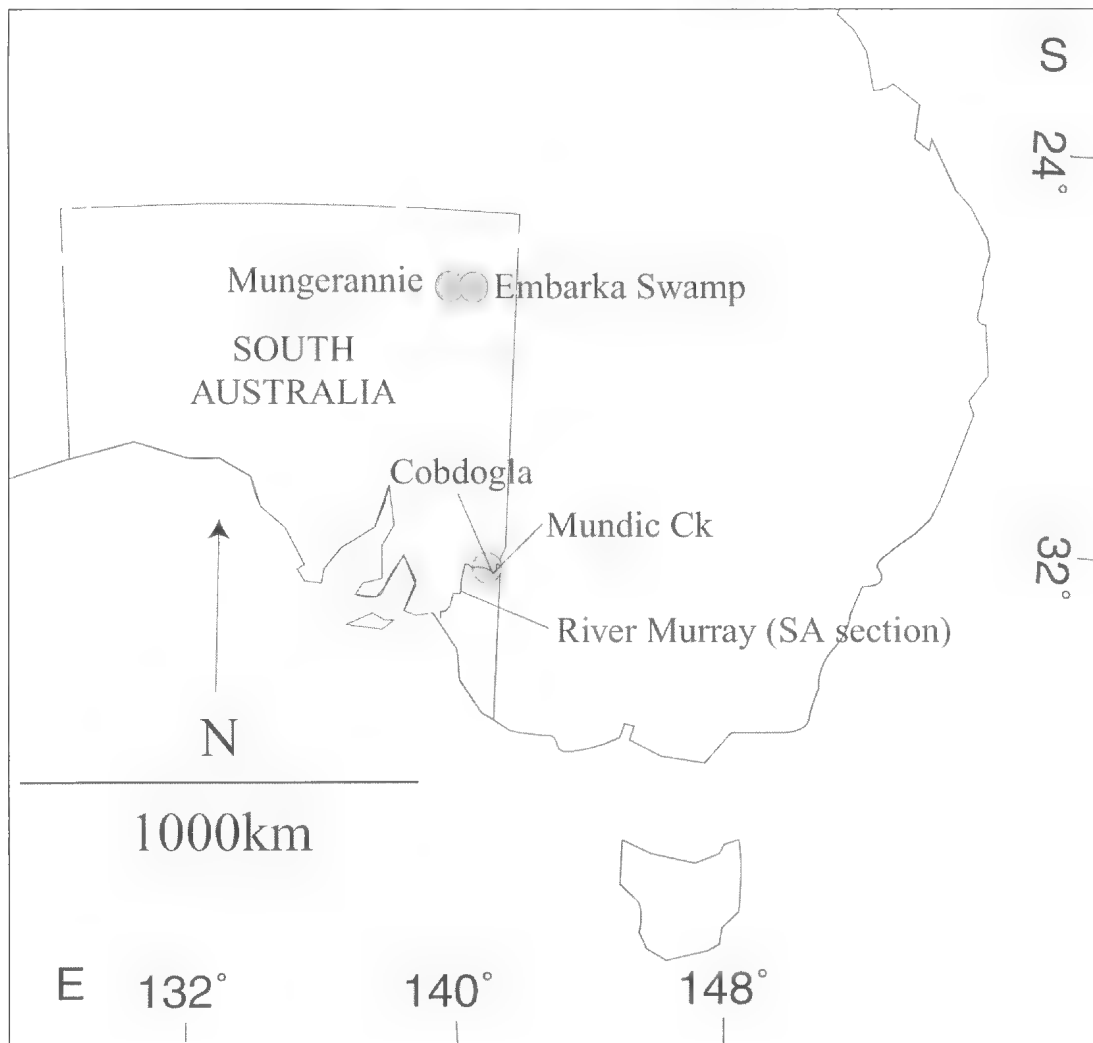


Fig. 1. Map of Australia showing collection localities in the state of South Australia.

yields of carbon-dioxide baited traps against that of human biting collections to determine whether both methods reveal the same temporal host-seeking patterns in *Cx. annulirostris*, thereby providing a more precise and safer alternative sampling method. In addition, this investigation will enable previously reported host-seeking rhythms for this species (Standfast & Fieldhouse 1963; Russell 1987a,b) to be verified.

Methods

Human biting catch

Temporal host-seeking rhythms of wild *Cx. annulirostris* populations were determined by a series of all night human-biting catches. For 10

minutes each hour from one hour before sunset to two hours after sunrise, biting mosquitoes were collected from the lower legs (from the knee down) and feet (of CRW) using a mouth operated aspirator. Mosquitoes collected each hour were stored in cups covered with gauze for identification and counting in the laboratory.

All-night biting collections were made on eleven occasions from January 1999 to January 2001, in two regions of South Australia (SA): in northeast SA and the Upper River Murray (Figure 1). In northeast SA, two collections (Jan. 26 and Feb. 16 1999) were made at Embarka Swamp (27° 37' S, 140° 10' E) and three (Jan. 26 – 28 2001) at Mungerannie (27° 59' S, 138° 36' E). In the Upper River Murray, two collections (Feb. 2 and 13 2000) were made at

Cobdogla (34° 14' S, 140° 24' E) and four (Jan. 5, 7 and 18 2001) at Mundic Creek (34° 11' S, 140° 46' E).

The number of female *Cx. annulirostris* collected each hour was converted to a proportion of the total catch that particular night. These values were used to calculate the overall mean proportion each hour of the total *Cx. annulirostris* collected for both regions. Temporal host-seeking rhythms in the two regions were compared using a General Linear Model (GLM) with a repeated measures procedure in SPSS computer software (Release 11.0.1, 2003, SPSS Inc. Chicago, USA). This model was used to assess region by hour interactions.

Serial carbon-dioxide baited trapping

Carbon-dioxide baited miniature light traps (Rohe & Fall 1979) were used to measure the temporal host-seeking pattern of *Cx. annulirostris* at Mungerannie in northeast SA and at Mundic Creek on the Upper River Murray.

Three traps, in a roughly triangular arrangement, each separated by 100–110 m, were set in trees, 1.5–2 m above the ground. 1.1 kg of dry-ice pellets (approximately 2 x 1 cm each) was used as the carbon-dioxide source for each trap. Traps were operated from one hour before sunset throughout the night until two hours after sunrise. At the end of each hour, the catch bag on each of the three traps was replaced. The catch for the previous hour was immediately killed on dry ice and stored in separate sample jars for each trap for later identification and counting in the laboratory. This procedure was repeated for three nights at Mungerannie (Jan. 25–27 2001) and three nights at Mundic Creek (Jan. 5–7 2001).

The number of female *Cx. annulirostris* captured in each trap per hour was converted to a proportion of the total catch from that trap for a particular night. These values were used to calculate the mean proportion and 95% confidence limits of the total *Cx. annulirostris* trapped in each hour for each night.

Comparison of sampling methods

On five occasions, human biting catches and hourly carbon-dioxide baited trapping were undertaken concurrently at sites approximately 200 m apart. This occurred at Mundic Creek on Jan. 5, 6 and 7 2001, and at Mungerannie on Jan. 26 and 27 2001. This enabled linear correlations to be made (using JMP-IN[©] statistical software [SAS Institute Inc. 1997]) between the number of *Cx. annulirostris* caught at each hour by human-biting catch and carbon dioxide baited trapping.

Results

Human biting catch

1211 *Cx. annulirostris* were caught biting at sites in northeast SA while 1194 were caught in the Upper River Murray region. Host-seeking periodicity differed between the two regions. In northeast SA, host-seeking only began after sunset, decreasing initially, then increasing until a peak six hours later, before decreasing steadily until sunrise (Figure 2). There was no host-seeking activity in the two hours after sunrise. At the Upper River Murray sites, no host-seeking occurred until after sunset, after which the maximum host-seeking activity was observed (Figure 2). This steadily decreased throughout the night before a slight elevation in activity was observed at sunrise. There was no activity in the two hours after sunrise.

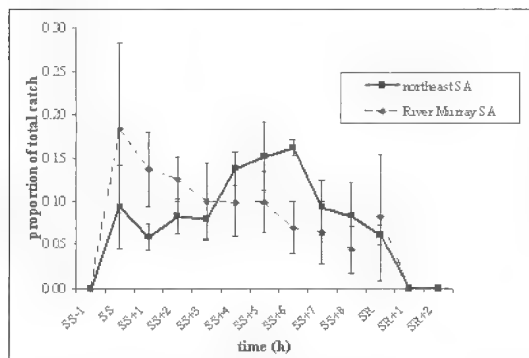


Fig. 2. Temporal host-seeking rhythm of *Culex annulirostris* from two geographically isolated populations as determined by human-biting catch. Values presented are mean proportions of the total catch each hour (\pm 95% confidence intervals). SS = sunset, SR = sunrise.

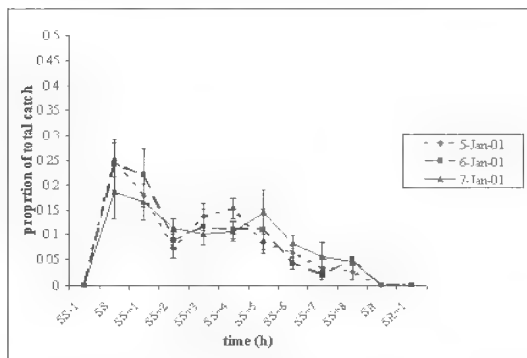


Fig. 3. Temporal host-seeking rhythm of *Culex annulirostris* from the Upper River Murray region as determined by hourly catches using carbon-dioxide baited traps. Values presented are mean proportion of the total catch each hour (\pm 95% confidence intervals). SS = sunset, SR = sunrise.

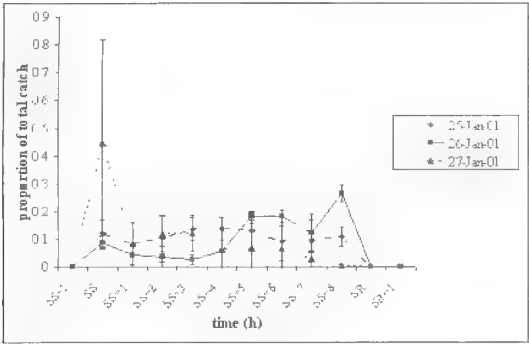


Fig. 4. Temporal host-seeking rhythm of *Culex annulirostris* from northeast SA as determined by hourly catches using carbon-dioxide baited traps. Values presented are mean proportion of the total catch each hour (\pm 95% confidence intervals). SS = sunset, SR = sunrise.

Differences between the host-seeking rhythms in the two regions are apparent in the amount of activity in the hour after sunset (lower in northeast SA), and in the activity six hours after sunset (lower at the Upper River Murray) (Figure 2). These differences were confirmed by the GLM procedure, which detected significant region by hour interactions ($F = 3.351$, $P = 0.044$).

Carbon-dioxide baited trapping

The periodicity of *Cx. annulirostris* host-seeking at the Upper River Murray peaks at sunset, then steadily decreases throughout the night (Figure 3). All three sampling nights revealed a similar pattern.

In northeast SA, a periodicity over the three sampling nights was not apparent, with one night showing a peak in activity at sunset, while another showed a peak at sunrise (Figure 4).

Correlations between human-biting catch and carbon-dioxide baited trapping

Statistically significant correlations between the numbers of mosquitoes captured by human-biting catch and serial carbon-dioxide baited trapping were detected for four of the five nights during which both methods were used concurrently (Table 1). Correlations returned r values from 0.539 at Mungerannie on 26/i/01, to 0.877 at Mundic Creek on 5/i/01.

Discussion

In the Upper River Murray region, human-biting catch revealed a nocturnal host-seeking pattern with crepuscular peaks in activity. This is consistent with the findings of previous studies (Standfast & Fieldhouse 1963; Russell 1987a). Hourly catches in

TABLE 1. Results for linear correlations of hourly mosquito capture using two methods: human biting catch and carbon dioxide baited traps.

Date	Location	r	P
Jan 5, 2001	Mundic Creek, Upper River Murray region	0.877	$P < 0.001$
Jan 6, 2001	Mundic Creek, Upper River Murray region	0.681	$0.01 < P < 0.02$
Jan 7, 2001	Mundic Creek, Upper River Murray region	0.779	$0.002 < P < 0.005$
Jan 26, 2001	Mungerannie, northeast SA	0.539	$0.05 < P < 0.10$
Jan 27, 2001	Mungerannie, northeast SA	0.436	$0.01 < P < 0.02$

carbon-dioxide baited traps revealed the same pattern, except with a smaller dawn activity peak. Surprisingly, human-biting catch revealed a different host-seeking pattern in northeast SA. Although host-seeking was nocturnal in that region and there was a small peak at sunset, maximum activity was much later in the night, at six hours after sunset.

The data probably represent an innate behavioural difference between *Cx. annulirostris* in the two regions. Other behavioural heterogeneities in this species (such as host-odour preference) between these regions have been discovered (Williams *et al.* 2003). Such variation may influence the degree to which different hosts are attacked, and may in turn influence the ecology of mosquito-borne disease in different regions. Understanding this variation is crucial to effective mosquito-borne disease management.

However, the impact of environmental factors on mosquito behaviour in this study cannot be discounted, even though records of meteorological data indicate little difference between the regions on the sampling dates (C. R. Williams unpublished data).

While the correlations between the hourly carbon-dioxide baited trap catch and the human-biting catch were significant in four of five cases, the strength of linear correlations (r values) was variable. Correlations were stronger at the Upper River Murray than in northeast SA (Table 1). Given the variability of hourly catches using traps in northeast SA (Figure 4) and the relative consistency of results by human-biting catch method there (Figure 2), very strong correlations were not expected. Furthermore, on the first night of this trapping in northeast SA (25/i/01), heavy rainfall for three hours (Sunset +4 – Sunset +7 hours) may have inhibited host-seeking behaviour. Human-biting catch was not undertaken on this date, and was thereby spared from this meteorological influence.

Furthermore, correlations may have been stronger had hourly collections been made from several humans concurrently. This may have controlled for variability in mosquito attractiveness that exists between humans (Khan 1977; Schreck *et al.* 1990; Lindsay *et al.* 1993; Knols *et al.* 1995). Despite this, four out of five correlations were statistically significant.

This study, the first to compare hourly captures of host-seeking mosquitoes using two different methods, has shown that hourly carbon-dioxide baited trapping may provide an alternative to human-biting catch. This in turn may provide a method which poses a far lower disease risk to investigators.

As this study focused on a crepuscular/nocturnal

mosquito species (*Cx. annulirostris*), extrapolation of these findings to diurnal species (such as *Aedes aegypti* (L.) and *Ae. albopictus* [Skuse]) should be done with caution.

Acknowledgments

Nick Souter and Ben Smith generously provided field assistance. Fred Stace constructed carbon-dioxide baited traps. David Kokkinn sorted numerous mosquito collections in the laboratory. CRW was in receipt of a University of South Australia postgraduate award and received financial assistance from the School of Pharmaceutical, Molecular and Biomedical Sciences.

References

- CHARTWOOD, J. D. & WILKES, T. J. (1979) Studies on the age-composition of samples of *Anopheles darlingi* (Diptera: Culicidae) in Brazil. *Bull. Ent. Res.* **69**, 337-342.
- DAVIS, J. R., HALL, T., CHEE, E. M., MAJALA, A., MINJAS, J. & SHIFF, C. J. (1995) Comparison of sampling anopheline mosquitoes by light-trap and human-bait collections indoors at Bagamoyo, Tanzania. *Med. Vet. Entomol.* **9**, 249-255.
- HADDOW, A. J. & SSENKUBUGE, Y. (1965) Entomological studies from a high tower in Zika Forest, Uganda I. The biting activity of mosquitoes and Tabanids as shown by twenty-four-hour catches. *Trans. R. Ent. Soc. Lond.* **117**, 215-243.
- KAY, B. H. (1985) Man-mosquito contact at Kowanyama northern Queensland, Australia. *J. Am. Mosq. Cont. Assoc.* **1**, 191-194.
- BOREHAM, P. F. L. & FANNING, I. D. (1985) Host-feeding patterns of *Culex annulirostris* and other mosquitoes (Diptera: Culicidae) at Charleville, southwestern Queensland, Australia. *J. Med. Entomol.* **22**, 529-535.
- KHAN, A. A. (1977) Mosquito attractants and repellents. In H. H. Shorey, H. H. & McKelvey Jr, J. J. (Eds) "Chemical Control of Insect Behaviour", pp. 305-325. (John Wiley & Sons, New York).
- KNOLS, B. G. J., DE JONG, R. & TAKKEN, W. (1995) Differential attractiveness of isolated humans to mosquitoes in Tanzania. *Trans. R. Soc. Trop. Med. Hyg.* **89**, 604-606.
- LEE, D. J., HICKS, M. M., DEBENHAM, M. L., GRIFFITHS, M., MARKS, E. N., BRYAN, J. H. & RUSSELL, R. C. (1989) "The Culicidae of the Australasian Region Volume 7", Entomology Monograph No. 2. Australian Government Publishing Service, Canberra.
- LINDSAY, S. W., ADIAMAH, J. H., MILLER, J. E., PLEASS, R. J. & ARMSTRONG, J. R. M. (1993) Variation in attractiveness of human subjects to malaria mosquitoes (Diptera: Culicidae) in The Gambia. *J. Med. Entomol.* **30**, 368-373.
- LINES, J. D., CURTIS, C. F., WILKES, T. J. & NJUNWA, K. J. (1991) Monitoring human-biting mosquitoes (Diptera: Culicidae) in Tanzania with light-traps hung beside mosquito nets. *Bull. Ent. Res.* **81**, 77-84.
- LUDUEÑA ALMEIDA, F. F. L. & GORLA, D. E. (1995) Daily pattern of flight activity of *Aedes albifasciatus* in Central Argentina. *Mem. Inst. Oswaldo Cruz* **90**, 639-644.
- MACKENZIE, J. S., BROOM, A. K., HALL, R. A., JOHANSEN, C. A., LINDSAY, M. D., PHILLIPS, D. A., RITCHIE, S. A., RUSSELL, R. C. & SMITH, D. W. (1998) Arboviruses in the Australian region, 1990 to 1998. *Comm. Dis. Intell.* **22**, 93-100.
- MAITINGLY, P. F. (1949) Studies on West African forest mosquitoes Part II - the less commonly occurring species. *Bull. Ent. Res.* **40**, 387-402.
- MITCHELL, L. (1982) Time-segregated mosquito collections with a Center for Disease Control miniature light trap. *Mosq. News* **42**, 12-18.
- REISEN, W. K., LOTHIROP, H. D. & MEYER, R. P. (1997) Time of host-seeking by *Culex tarsalis* (Diptera: Culicidae) in California. *J. Med. Entomol.* **34**, 430-437.
- ROHE, D. L. & FALL, R. P. (1979) A miniature battery powered CO₂ baited light trap for mosquito borne encephalitis surveillance. *Bull. Soc. Vect. Ecol.* **4**, 24-27.
- RUSSELL, R. C. (1987a) Host attraction studies of *Culex annulirostris* Skuse (Diptera: Culicidae) near Echuca, in the Murray Valley of Victoria. *J. Aust. Ent. Soc.* **26**, 375-378.
- (1987b) The mosquito fauna of Conjoia State Forest on the south coast of New South Wales. Part 2. Female feeding behaviour and flight activity. *Gen. Appl. Entomol.* **19**, 17-24.
- (1995) Arboviruses and their vectors in Australia: an update on the ecology and epidemiology of some mosquito-borne arboviruses. *Rev. Med. Vet. Entomol.* **83**, 141-158.
- (2002) Ross River virus: ecology and distribution. *Ann. Rev. Entomol.* **47**, 1-31.
- SAS INSTITUTE INC. (1997) "JMP IN" (Computer program). Belmont: Duxbury Press.
- SCHIRECK, C. E., KLINE, D. L. & CARLSON, D. A. (1990) Mosquito attraction to substances from the skin of different humans. *J. Am. Mosq. Cont. Assoc.* **6**, 406-410.
- STANDEFAST, H. A. & FIELDHOUSE, B. (1963) Arthropod-borne viruses: bionomics and taxonomy. *Ann. Rep. Qld Inst. Med. Res.* **18**, 7.
- VAIDYANATHAN, R. & EDMAN, J. D. (1997) Sampling with light traps and human bait in epidemic foci for eastern equine encephalomyelitis virus in southeastern Massachusetts. *J. Am. Mosq. Cont. Assoc.* **13**, 348-355.
- WILLIAMS, C. R., KOKKINN, M. J., SMITH, B. P. (2003) Intraspecific variation in odour-mediated host preference of the mosquito *Culex annulirostris*. *J. Chem. Ecol.* **29**, 1889-1903.

DEATHS OF KILLER WHALES (ORCINUS ORCA) IN SOUTH AUSTRALIA AND IMPLICATION OF HUMAN INTERACTION

BY *S. E. GIBBS*^{1,2}, *C. M. KEMPER*¹, *R. W. BYARD*³ & *M. LONG*¹

Summary

Gibbs, S. E., Kemper, C. M., Byard, R. W. & Long, M. (2004) Deaths of killer whales (*Orcinus orca*) in South Australia and implication of human interaction. *Trans. R. Soc. S. Aust.* 128(2), 231-237, 30 November, 2004.

In November, 1999 an adult female killer whale (*Orcinus orca*) was seen dead and floating off Tumby Bay, Spencer Gulf, South Australia. The body was never recovered, despite searching. The next day a juvenile killer whale, possibly the offspring of the adult off Tumby Bay, stranded alive twice and returned itself to sea at Tulka, about 50 km south of the adult. The 3.72 m juvenile subsequently washed up in a decomposed state at Emu Bay, Kangaroo Island. Cause of death was not established for either animal. The juvenile's stomach contained more than 20 kg of food, all recognisable parts being dolphin remains. These included two intact flippers, one tail stock, sizeable pieces of skin and dermis from the head and other unknown parts of the body, smaller pieces of semi-digested flesh, and defleshed bones from various regions of the skeleton. Most dolphin parts were identified as the Indo-Pacific bottlenose dolphin, *Tursiops aduncus*, but some bones were possibly from a short-beaked common dolphin, *Delphinus delphis*, and some were from an unknown species of dolphin. Remains from at least five individual dolphins were present in the stomach. Forensic examination concluded that most of the larger pieces of skin and dermis had been cut with a sharp-edged blade, and implicated human interaction with dead or live dolphins and possibly the juvenile killer whale. Such activities are illegal in South Australian waters. More information is needed on interactions between killer whales and humans in Australian waters.

Key Words: Killer Whale, *Orcinus orca*, Dolphin, Human, Interactions, Cetacean, Diet.

DEATHS OF KILLER WHALES (*ORCINUS ORCA*) IN SOUTH AUSTRALIA AND IMPLICATION OF HUMAN INTERACTION

by S. E. GIBBS^{1,2}, C. M. KEMPER¹, R. W. BYARD³ & M. LONG¹

Summary

GIBBS, S. E., KEMPER, C. M., BYARD, R. W. & LONG, M. (2004). Deaths of killer whales (*Orcinus orca*) in South Australia and implication of human interaction. *Trans. R. Soc. S. Aust.* 128(2), 231-237, 30 November, 2004.

In November 1999 an adult female killer whale (*Orcinus orca*) was seen dead and floating off Tumby Bay, Spencer Gulf, South Australia. The body was never recovered, despite searching. The next day a juvenile killer whale, possibly the offspring of the adult off Tumby Bay, stranded alive twice and returned itself to sea at Tulka, about 50 km south of the adult. The 3.72 m juvenile subsequently washed up in a decomposed state at Emu Bay, Kangaroo Island. Cause of death was not established for either animal. The juvenile's stomach contained more than 20 kg of food, all recognisable parts being dolphin remains. These included two intact flippers, one tail stock, sizeable pieces of skin and dermis from the head and other unknown parts of the body, smaller pieces of semi-digested flesh, and defleshed bones from various regions of the skeleton. Most dolphin parts were identified as the Indo-Pacific bottlenose dolphin, *Tursiops aduncus*, but some bones were possibly from a short-beaked common dolphin, *Delphinus delphis*, and some were from an unknown species of dolphin. Remains from at least five individual dolphins were present in the stomach. Forensic examination concluded that most of the larger pieces of skin and dermis had been cut with a sharp-edged blade, and implicated human interaction with dead or live dolphins and possibly the juvenile killer whale. Such activities are illegal in South Australian waters. More information is needed on interactions between killer whales and humans in Australian waters.

KEY WORDS: Killer Whale, *Orcinus orca*, Dolphin, Human, Interactions, Cetacean, Diet.

Introduction

Killer whales (*Orcinus orca*) occur in continental shelf waters off all Australian states (Bannister *et al.* 1996) but little is known of their biology and diet in the region. They are often sighted in South Australian waters, particularly off the open ocean coasts but also from time to time in the shallow habitats of Spencer Gulf and Gulf St. Vincent (Cotton 1943; Ling 1991; unpublished records of South Australian Museum).

Off northwestern North America and in the Antarctic, at least two ecological groups are known; one feeding primarily on marine mammals and the other primarily on fish and cephalopods (Berzin & Vladimirov 1983; Felleman *et al.* 1991; Dalheim & Heyning 1999; Pitman and Ensor 2003). Common dolphins (*Delphinus* spp.), but not bottlenose dolphins (*Tursiops* spp.), are included in the diet of killer whales (Jefferson *et al.* 1991). Killer whales are also known to scavenge discards from net fishing vessels and take hooked fish (e.g. tuna and trevalla) from longlines (Dahlheim & Heyning 1999; Morrice *et al.* 2002). Interactions between killer whales and the commercial fishery, including longlines, off New Zealand sometimes result in the whales being illegally shot (Visser 2000).

In November 1999, the South Australian Museum (SAM) received two reports of killer whales in western Spencer Gulf, South Australia: a large animal floating dead off Tumby Bay and a live-stranded juvenile at Tulka, 50 km further south. What is believed to be the same juvenile subsequently washed up dead on Kangaroo Island and was collected by the South Australian Museum. This study reports on the circumstances surrounding these events and analysis of samples, including stomach contents, collected from the juvenile. It also reviews records of apparent feeding behaviour of killer whales in South Australia.

Materials and Methods

The carcass of the juvenile killer whale was dissected on the beach 4 km ENE of Emu Bay, Kangaroo Island (35° 36' S, 137° 33' E) on 8 December 1999 by M. Long (SAM) and M. Jones (RSPCA) with the assistance of officers of National Parks and Wildlife, SA. Body measurements were taken according to Baker (1990). Photographs of various parts of the body were taken before dissection and these were compared with video documentation of the live-stranded killer whale at Tulka. The full skeleton was collected and later cleaned by maceration at the SAM. Samples of liver, kidney, muscle and skin, were preserved in saturated salt solution for genetic analysis, and liver, kidney, muscle and blubber frozen for toxic contaminant analysis. The skeleton and associated samples are lodged in the SAM (registration number M21244).

¹ South Australian Museum, North Terrace, Adelaide, SA, 5000.

² Present address: Macquarie University, Sydney, NSW, 2109.

³ Forensic Science Centre, Divett Place, Adelaide, SA, 5000.

Contact details: S. Gibbs email: sgibbs@gsa.mq.edu.au



Fig. 1. Floating carcass of female adult killer whale. Note swollen mammary area (Photo N. Kopman, 12 November 1999).

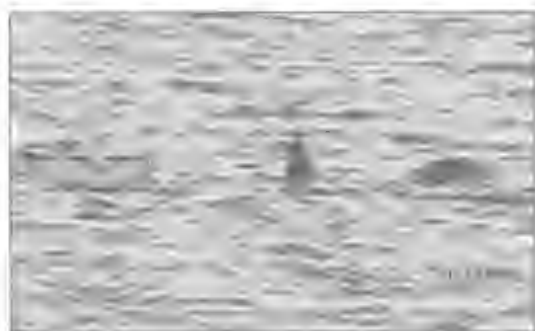


Fig. 2a and b. Photos of tail 'tear' confirming same individual, a) killer whale stranded at Tulka (Photo extracted from video footage by M. Stockholme, 13 November 1999), b) Tail of killer whale washed ashore at Emu Bay (SAM M21244, view from underside) (Photo M. Long, 8 December 1999).

The entire gastrointestinal tract (GIT) was removed and frozen for later examination at the SAM. There it was thawed and the stomach contents removed and weighed. Large, undigested items were separated from the remaining contents, refrozen and examined at a later date. The stomach and intestines were then flushed separately with water. Washings were screened through a 0.5-mm Endocell Sieve and examined with the aid of a magnifying lamp. Intact flippers found in the stomach were radiographed and measured. These and other contents were then macerated in warm water to clean the bones.

All bones were identified to the lowest possible

taxon after comparison with postcranial skeletons of small delphinid species in the collections of the SAM and Western Australian Museum (i.e. *Tursiops aduncus*, *T. truncatus*, *Delphinus delphis*, *Stenella coeruleoalba*, *S. longirostris*, *S. attenuata*, *Peponocephala electra*, *Lagenodelphis hosei*). Relative age of the bones was determined by comparison with skeletons of different sizes and states of physical maturity.

Large pieces of skin and dermis from the stomach contents were subject to forensic examination by R. Byard (Forensic Science Centre case no. 011183), with a view to determining whether human

involvement was implicated. Samples of liver and kidney were also taken for toxicological screening for common pesticides using routine gas and liquid chromatography methods, and portions of stomach contents were examined for heavy metals qualitatively using the Reinsch test.

Sexual and physical maturity of the killer whale were determined by comparing body length, degree of fusion of vertebral epiphyses and the amount of occlusion of the tooth pulp cavity (Perrin & Myrick 1980) with information from studies elsewhere.

Results

Anatomical examination

The carcass of the large killer whale seen floating dead about 10 km offshore between Tumby Bay and Winceby Island on 12 November 1999 was estimated by the observer, N. Kopman, to have been about 25 feet long (~7.6 m). Photographs provided to the SAM were of the ventral side and verified that the animal was female. Prominent swellings adjacent to the urogenital slit suggest that it was lactating (Fig. 1). The carcass was very fresh and the colour pattern and body shape, distinctly killer whale. There were no obvious injuries visible in the photographs. A public appeal to relocate the carcass during the following few weeks was unsuccessful.

On 13 November a juvenile killer whale (total length about 4 m) stranded alive twice in shallow water on the tidal flats at Tulka, Port Lincoln Proper, about 50 km SSW of where the large dead animal had been seen on 12 November. The juvenile successfully returned itself to deep water and swam off. Video footage of the animal showed a distinctive 'tear' on the trailing edge of the left fluke (Fig. 2a).

On 7 December a 3.72 m killer whale (Fig. 2b, 3) was found dead and in an advanced state of decomposition near Emu Bay on the north coast of Kangaroo Island and about 180 km SE of Tulka. Residents of Emu Bay reported that it had not been ashore for more than a few days when it was discovered. External (high dorsal fin, paddle-shaped flippers, distinctive white patches in the urogenital region and on the side of the head) and skull (teeth large and kidney-shaped in cross section, 12 alveoli upper, 11 alveoli lower) features confirmed the species identification (Table 1). Dissection of a testis confirmed that it was a male. The carcass was in an advanced state of decomposition (code 4, Geraci and Lounsbury 1993). No obvious penetrating wounds were found and the body had not been mutilated. There was no fluid or froth present in the lungs. The carcass did not appear to be emaciated. A distinctively shaped, healed 'tear' was observed on the trailing edge of the left fluke (Fig. 2b).

The skeleton was physically immature: no fusion of



Fig. 3. Photo showing the distinguishing features of juvenile killer whale SAM M21244 (Photo M. Long, 8 December 1999).

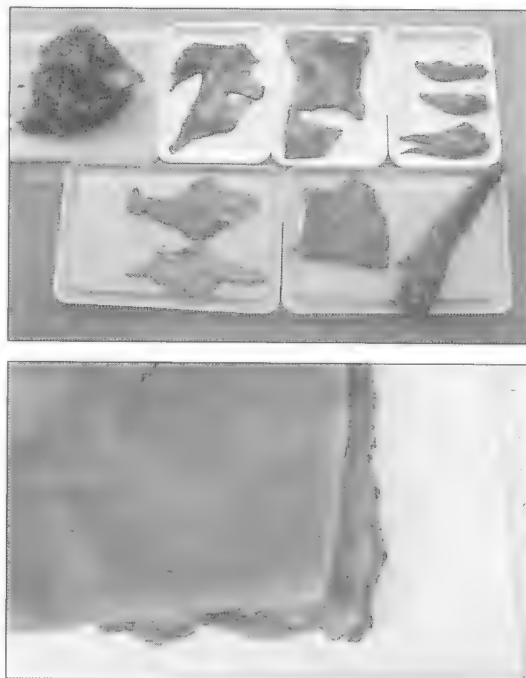


Fig. 4. Large items found in the stomach of the juvenile killer whale (SAM M21244), (lower photo) note cut edges (Photo S. Gibbs).

epiphyses to the centra along the length of the vertebral column or of epiphyses to the humerus, radius and ulna; some vertebrae with neural spines not completely fused to their centra; the suture between the maxilla and frontal not fused. The pulp cavities of the teeth were fully open. The fourth to last caudal vertebra showed evidence of past injury on its left side—bone was growing over the damaged portion.

Analysis of the juvenile killer whale liver for organochlorines, carbamates, rodenticides, 1080 or

strychnine failed to reveal any evidence that the animal was poisoned by these substances.

Stomach contents and forensic examination

The stomach contained more than 20 kg of food. The actual weight was not ascertained due to the state of decomposition and difficulty in separating parts of the stomach itself (e.g. stomach lining) from

the contents. The stomach contents included both relatively undigested pieces and pieces showing more advanced digestion and/or decomposition. All identifiable items in the stomach were parts of small cetaceans. Undigested parts (Fig. 4) included flesh with skin intact, two intact flippers (approximate length 160 mm, width 75 mm), one tail stock with flukes removed, one fluke (approximate length 260 mm) and a piece of skin and flesh that had been removed from the left side of a skull (gape approximate length 270 mm).

Many of the undigested stomach contents showed sharply defined incised edges (Fig. 4). There were also smaller, deeply-incised, full thickness 'stab' wounds. The incised wounds were quite consistent with post mortem butchering, although given the fragmented and putrefied nature of the tissues it was not possible to exclude the possibility that some of the injuries had been inflicted antemortem. The fragmented nature of the specimens also precluded an assessment as to the nature of the weapon that had been used to inflict the wounds other than to note that it was characterized by a sharp edge, such as is found on a knife. There were no projectiles found or projectile wounds discernable. The stomach contents also contained items in a more advanced state of digestion and/or decomposition, including many bones. These are listed in Table 2 and have been grouped into likely associations based on species identity, relative age and amount of degeneration.

TABLE 1. *Measurements of a juvenile male killer whale washed up near Emu Bay, Kangaroo Island in early December 1999 (SAM M21244).*

Feature	Measurement (mm)
Total length	3720
Tip of upper jaw to centre of eye	480
Length of gape	470
Tip of upper jaw to blowhole	600
Tip of upper jaw to anterior insertion of flipper	810
Tip of upper jaw to dorsal fin	2020
Tip of upper jaw to centre of anus	2580
Maximum girth	2340
Length of flipper	610
Width of flipper	280
Width of tail flukes	1020
Depth of tail notch	50
Height of dorsal fin	455
Ventral blubber thickness	34
Dorsal blubber thickness	39

TABLE 2. *Species identification and relative age of loose bones and macerated intact body parts from the stomach of a juvenile killer whale washed up near Emu Bay, Kangaroo Island (SAM M21244). Bones grouped according to whether they are likely to be from the same animal.*

Body part	Species	Relative age	Material
Flipper/shoulder	A. <i>Tursiops cf aduncus</i>	Young	Left and right flippers without scapulae
	B. <i>Tursiops cf aduncus</i>	Young	1 intact humerus
			1 intact radius
			1 intact ulna
			1 intact left scapula
	C. dolphin	Not very old	4 phalanges
	D. <i>Tursiops cf aduncus</i>	Aged animal	1 part-digested humerus
			1 part-digested ulna
			1 part-digested radius
			1 almost wholly-digested scapula
Throat Thorax	E. <i>Delphinus delphis?</i>	Not young	1 partly-digested scapula
	F. dolphin	Aged animal	1 complete hyoid apparatus
	G. <i>Tursiops cf aduncus</i>	Young	2 parts of sternum
			22 true ribs
			24 costal ribs
			21 thoracic and lumbar vertebrae
			40 vertebral epiphyses
	H. dolphin	Not young?	4 ribs or part ribs
	I. dolphin	?	Vertebral fragments
	J. Unknown dolphin*	Aged animal	15 caudal vertebrae
Tail			11 chevrons

*Comparative skeletons not available for identification to species (see Materials and Methods).

Comparison of radiographs of the intact flippers with radiographs of known species of various relative ages showed that the two intact flippers found in the stomach contents appeared to belong to a juvenile *Tursiops aduncus*. Subsequent examination of the bones prepared from these flippers confirmed this (Table 2). The estimated number of dolphins represented in the stomach was at least five. This is based on the following combinations of body regions listed in Table 2: 1) one neonatal/juvenile *Tursiops cf aduncus* of about 1 m body length (part A); 2) one juvenile *Tursiops cf aduncus* of about 1.4 m body length (parts B and G), 3) one 'adult' *Tursiops cf aduncus* (parts D, F and possibly H), 4) one 'adult' of an unknown species of dolphin (part J). The skin from the side of the head (including gape) appeared to have come from a *Delphinus delphis* of about 1.8 to 2.0 m body length and may have been associated with the partly-digested scapula (part E).

Toxicological screening of fragments of dolphin retrieved from the stomach revealed no traces of mercury, bismuth or antimony.

Discussion

Killer whales of all ages, including juveniles and calves, and both sexes have been observed to participate in attacks on marine mammals with

subsequent feeding (Jefferson *et al.* 1991). It is not known whether killer whales off Australia conform to the marine mammal/fish-eating ecotypes studied elsewhere (Berzin & Vladimirov 1983; Felleman *et al.* 1991; Dalheim & Heyning 1999). However, there are anecdotal reports of possible feeding behaviour in South Australia (Table 3) and these suggest that large and small cetaceans and fish are attacked and/or consumed. The fact that both prey groups may be consumed by killer whales in South Australia could indicate a catholic diet of one population or that more than one ecotype is found in this region.

Killer whales are born at 2.1 to 2.5 m and weaned at about 4.3 m (Heyning & Dalheim 1988). The 3.72 m animal that washed up at Emu Bay was therefore too large to be a neonate and may or may not have been weaned. The presence of solid food in the stomach is not a good indicator of weaning in killer whales, because solids have been found in unweaned animals as small as 2.6 m (Heyning 1988). The age of the Emu Bay animal was estimated at about 2 years, based on comparison with a small data set of animals of known age and length from Norway (Christensen 1984).

Haenel (1986) divided killer whale behavioural ontogeny into four stages: infancy, juvenile, adolescence and maturity. During infancy (0-2 years), the calf spends most of the time with its mother, although towards the end of that period it

TABLE 3. Anecdotal reports of feeding behaviour of killer whales in South Australia. 'Prey' means possible prey, since it is not always proven that the species was eaten.

Behaviour and 'prey' species	No. killer whales	Location	Date	Source of data
Eating tuna	N/A	Off Robe	N/A	SAM records
Attacking other whales	11	4 km SE Port Macdonnell	10 December 1942	Cotton 1943
Herding salmon	52	Cape Jervis, Fleurieu Peninsula	1 June 1986	Ling 1991*
Large chunk of meat in mouth of one whale	5	Smoky Bay, Eyre Peninsula	9 March 1988	SAM records
Attacking 2 large whales	2	5-7 km ENE Troubridge Shoal	3 May 1988	Ling 1991
Harassing a common dolphin	7	Point Brown	2 March 1990	Ling 1991, SAM records
Chasing 'porpoise'	6	3 km W Cape Jervis, Fleurieu Peninsula	9 November 1991	SAM records
Carrying small dead dolphin in mouth	3	Pondalowie Bay, Yorke Peninsula	25 December 1991	SAM records
Attacking daisy formation of sperm whales, much blood in water	19 or 20	Great Australian Bight, 250 km SW Port Lincoln	10 March 1992	SAM records
Pursuing sperm whales	15	~125 km S Eucla	13 February 1997	SAM records
Circling and chasing school of salmon	>6	Cape du Couedic, Kangaroo Island	17 July 1997	SAM records
Catching snapper	3	Smoky Bay, Eyre Peninsula	27 April 2000	SAM records
Catching snapper and possibly seal	N/A	Smoky Bay, Eyre Peninsula	2 May 2000	SAM records

* Ling (pers. comm. 2004) notes that he now doubts that these were indeed killer whales, in the absence of any other reports of such a spectacular event.

increases the amount of time with other members of the pod. At about 2 years old, it enters the juvenile phase (2–6 years), characterized by great activity and curiosity, and their bold inquisitiveness often leads to them approaching boats. It is therefore possible that the juvenile killer whale that washed up near Emu Bay took butchered parts of dolphin from some human activity. The presence of undigested dolphin remains suggests that the interaction had taken place shortly before or at the time of the killer whale's death.

Piecing together the events around the time of its live stranding and subsequent death, we can hypothesise what might have happened. The adult female killer whale that was observed floating dead off Tumby Bay on 12 November may have been the mother of the juvenile that stranded and subsequently died. No live killer whales were seen when the juvenile stranded at Tulka yet one would expect that a lactating female would not normally desert her dependent calf (Haenel 1986). We conclude, therefore, that the juvenile's mother may have died. Without its mother and perhaps separated from its natal pod, the juvenile would not have known how to hunt and may have taken dolphin pieces given to it by humans or raided fishing operations in which dolphin carcasses were being illegally used as bait. The presence of both digested and undigested dolphin remains in the juvenile's stomach suggests that the dolphins or parts thereof were consumed over a period of time. Alternatively, if the dolphin pieces were in various states of decomposition at the time the killer whale consumed them, this suggests that the dolphins had died at different times and had been stored possibly for bait. The second scenario may account for the different species of dolphin, including the 'unknown' as they may have originated far from where they were consumed by the killer whale.

The cause of death of both killer whales was not established. The carcass of the juvenile was decomposed, a veterinarian was not present and the dissection was carried out on the beach; thus making it impossible to check for many natural and unnatural conditions. The fragmentary nature of the stomach contents combined with incomplete preservation, also made assessments of the possible presence or absence of lethal or non-lethal injuries in the pieces of dolphin difficult. While analyses of samples of stomach contents did not reveal any evidence of poisoning only a limited range of poisons were screened. The body of the adult female was never recovered despite a public appeal to find it. Such a

large animal in semi-enclosed Spencer Gulf should have been relatively easy to locate and even if sharks and other predators had started to eat it, the body would still float for weeks (SAM, unpublished data). The events surrounding the deaths of the killer whales point to suspicious human interactions involving both animals.

Whatever the circumstances of death of these killer whales, the presence of dolphin pieces with incised edges from a sharp blade suggests that illegal activities occurred. All cetaceans and pinnipeds are protected in South Australian waters under the South Australian *National Parks and Wildlife Act, 1972 (SA)*, *Fisheries Act 1982* and federal *Environment Protection and Biodiversity Conservation Act 1999*. These Acts make it an offence to kill, harass, molest or injure marine mammals and, under the Fisheries Act, it is also an offence to be in possession of a dead marine mammal or part thereof (D. Kelly pers. comm. 2003). Violations are not uncommon and there are many instances of intentional killing of cetaceans and pinnipeds in the last 10 years (Kemper *et al.* in press). A successful conviction was obtained in the case of crayfish fishing operators shooting common dolphins and using the carcasses for bait in craypots during April 1990 off the south coast of Kangaroo Island.

Public empathy for whales and dolphins has grown in recent times but there are still people who would harm and kill them despite legal protection of marine mammals. Killer whales, and other marine mammals, are especially disliked by persons who consider them a threat or nuisance to their activities or livelihood. More information is needed to prosecute offenders and this study demonstrates the importance of gathering rigorous data, including forensic studies, on carcasses that are found.

Acknowledgments

We would like to thank the following people for their contribution to this paper: Andy Warner National Parks and Wildlife SA, Mike Jones Royal Society for the Prevention of Cruelty to Animals for their assistance with collecting the Emu Bay juvenile; Marianne Stockholm for details and video of the live stranding; Neil Kopman for photos and information on the adult; Bob Hamilton-Bruce and volunteers who prepared the skeleton. Deb Kelly Department for Environment and Heritage for advice on legislation; J. Gardiner Forensic Science Centre for toxicological analyses. We thank Daniel Mau for producing images from the video.

References

- BAKER, A. (1990) "Whales and dolphins of Australia and New Zealand: An identification guide" (Victoria University Press, Wellington).
- BANNISTER, J. L., KEMPER, C. M. & WARNEKE, R. M. (1996) "The Action Plan for Australian Cetaceans. Wildlife Australia Endangered Species Program Project Number 380" (Environment Australia, Canberra).
- BERZIN, A. A. & VLADIMIROV, V. L. (1983) A new species of killer whale (Cetacea, Delphinidae) from Antarctic waters. *Zoologicheskii Zhurnal* **62**, 287-295.
- CHRISTENSEN, I. (1984) Growth and reproduction of killer whales, *Orcinus orca*, in Norwegian coastal waters. *Reports of the International Whaling Commission (Special Issue 6)*: 253-258.
- COTTON, B. C. (1943) Killer whales in South Australia. *The South Australian Naturalist* **22**, 2-3.
- DAHLHEIM, M. E. & HEYNING, J. E. (1999) Killer whale *Orcinus orca* (Linnaeus, 1758). Pp. 281-322. In *Handbook of Marine Mammals (Volume 6)* (Eds Ridgway, S. H. and Harrison, R. Academic Press (San Diego)).
- FELLEMAN, F. L., HEIMLICH-BORAN, J. R. & OSBORNE, R. (1991) The feeding ecology of killer whales (*Orcinus orca*) in the Pacific northwest. Pp. 113-148. In Pryor, K. & Norris, K. (Eds) "Dolphin Societies: Discoveries and Puzzles" (University of California Press Ltd., Oxford, England).
- GERACI, J. R. & LOUNSBURY, V. J. (1993) "Marine Mammals Ashore. A field guide for Strandings" (Texas A & M Sea Grant, Galveston).
- HAENEL, N. J. (1986) General notes on the behavioral ontogeny of Puget Sound killer whales and the occurrence of allomaternal behaviour. Pp. 285-300. In Kirkevold, B. C. & Lockard, J. S. (Eds) "Behavioral Biology of Killer Whales. Zoo Biology Monographs Volume 1" (Alan R. Liss Inc. New York).
- HEYNING, J. E. (1988) Presence of solid food in a young killer whale (*Orcinus orca*). *Marine Mammal Science* **4**, 68-71.
- & DAHLHEIM, M. E. (1988) *Orcinus orca*. *Mammalian Species* 304:1-9
- JEFFERSON, T. A., STACEY, P. J. & BAIRD, R. W. (1991) A review of killer whale interactions with other marine mammals: predation to co-existence. *Mammal Review* **21**(4):151-180.
- KEMPER, C. M., FLAHERTY, A., GIBBS, S. E., HILL, M., LONG, M. & BYARD, R. W. (in press) Cetacean captures, strandings and mortalities in South Australia 1881-2000 with special reference to human interactions. *Australian Mammalogy*.
- LING, J. K. (1991) Recent sightings of killer whales, *Orcinus orca* (Cetacea: Delphinidae), in South Australia. *Trans R. Soc. S. Aust.* **115**, 95-98.
- MORRICE, M., BELL, C., VAN DER HOFF, J., THIELE, D., GILL, P., PATON, D. & CHAMBELLANT, M. (2002) Killer whales (*Orcinus orca*) in Australian territorial waters - are they secure? Forth International Orca Symposium and Workshop 23-28 September 2002, Chize, France.
- PERRIN, W. F. & MYRICK, A. C. (Eds) (1980) Growth of odontocetes and sirenians: problems in age determination. *Reports of the International Whaling Commission (Special Issue 3)*.
- PITMAN, R. L. & ENSOR, P. (2003) Three forms of killer whales (*Orcinus orca*) in Antarctic waters. *Journal of Cetacean Research and Management* **5**(2), 131-139.
- VISSER, I. N. (2000) Killer whale (*Orcinus orca*) interactions with longline fisheries in New Zealand waters. *Aquatic Mammals* **26**(3), 241-252.

THE TENNYSON SAND DUNES: VEGETATION STRUCTURE AND CONSERVATION STATUS

By J. HINCHCLIFFE^{1,2} & J. G. CONRAN¹

Summary

Hinchcliffe, J. & Conran, J. G. (2004). The Tennyson sand dunes: vegetation structure and conservation status. *Trans. R. Soc. S. Aust.* 128(2), 239-248, 30 November, 1994. The Tennyson sand dunes represent one of the last largely natural dune communities along the Adelaide metropolitan coast, a region where there is a considerable effort being expended by local councils and community groups on revegetation for dune stability, habitat for native animals and for shoreline visual amenity. This study represents the first quantitative analysis of their vegetation. Fifty-two species were encountered, 22 of them exotic, and cluster analysis and ordination recovered three quadrat groups on the basis of species relative cover, representing fore-, mid-, and backdune quadrats.

Key Words: Coastal foredunes, vegetation structure, conservation, ordination.

THE TENNYSON SAND DUNES: VEGETATION STRUCTURE AND CONSERVATION STATUS

by J. HINCHCLIFFE^{1,2} & J. G. CONRAN¹

Summary

HINCHCLIFFE, J. & CONRAN J. G. (2004). The Tennyson sand dunes: vegetation structure and conservation status. *Trans. R. Soc. S. Aust.* 128(2), 239–248, 30 November, 2004.

The Tennyson sand dunes represent one of the last largely natural dune communities along the Adelaide metropolitan coast, a region where there is considerable effort being expended by local councils and community groups on revegetation for dune stability, habitat for native animals and for shoreline visual amenity. This study represents the first quantitative analysis of their vegetation. Fifty-two species were encountered, 22 of them exotic, and cluster analysis and ordination recovered three quadrat groups on the basis of species relative cover, representing fore-, mid- and backdune quadrats. These correlated with distance from the shore and increasing litter cover, agreeing with other dune studies. Recruitment of *Olearia axillaris* was associated mainly with exposed foredune sands and the large numbers of juveniles at the site imply that ongoing self-regeneration of the vegetation is occurring. Nevertheless, the dominance of introduced species is a cause for concern, and our findings provide baseline information for longer term management of dune stabilisation, key species, weeds and rare to endangered taxa.

KEY WORDS: Coastal foredunes, vegetation structure, conservation, ordination.

Introduction

Vegetation is fundamental in the formation and stabilisation of coastal sand dunes, providing habitat for a diverse range of animals (Chapman 1976; Viles & Spencer 1995). Australia's recent history of intense human activity along its coastline has resulted in the reduction and modification of much of its native coastal vegetation. The most obvious and direct impacts have been foreshore erosion, the replacement of coastal vegetation by housing development, the introduction of exotic plants and animals and disturbance by beach users and vehicles. Integrated approaches to management, which are essential in order to address these issues (Morcom 2002; Morcom & Harvey 2002), require a detailed understanding of the current dune condition, vegetation patterns and trends.

In many instances councils want to revegetate with native species but lack appropriate data on which to base selections. In the past, introduced species such as *Ammophila arenaria* (marram grass) and *Elymus farctus* (sea wheat-grass) were used widely for dune stabilisation, and dune stabilisation studies emphasised the advantages of introduced colonisers such as *Elymus* spp., *Cakile* spp. and *Ammophila* spp. over native species, particularly *Spinifex* spp. (Hesp 1984; Heyligers 1984, 1985; Bird & Jones

1988). Nevertheless, the germination ecology of Beach Spinifex (*Spinifex sericeus*) in Australia was studied to improve techniques for its use in revegetation (Harty & McDonald 1973).

Dune vegetation has long been recognised as a good model for long-term succession (Warming 1891), with early colonisation by sand-binding grasses followed with gradual displacement by shrubs or small trees (Olson 1958) creating characteristic zonation patterns (Boyce 1954; Gray 1985; Rozema *et al.* 1985; Partridge 1992). Walker *et al.* (1981) suggested that disturbance in older dune systems is likely to increase the rate of nutrient loss by causing vegetation decline, however, few Australian studies address changes produced by both succession and disturbance.

Early last century, Osborn (1914) noted that the visually dominant dune plants along the Adelaide metropolitan coast included *Olearia axillaris*, *Scaevola crassifolia*, *Lepidosperma gladiatum* as well as marram grass. Cleland (1932) and Fenner and Cleland (1932) surveyed the coastal vegetation between Outer Harbour and Sellick's Hill, listing 62 species, of which nine were introduced, including boxthorn (*Lycium ferocissimum*), evening primrose (*Oenothera stricta*), prickly saltwort (*Salsola kali*) and couch grass (*Cynodon dactylon*). Specht (1972) studied the dunes between Grange and Semaphore (including what is now the Tennyson dunes remnant), recognising a number of species groupings and emphasising the importance of succession in terms of distance from the foredune edge.

More recently, Opperman (1999) used multivariate techniques to define 52 floristically distinct coastal

¹ Centre for Evolutionary Biology and Biodiversity, Environmental Biology, School of Earth and Environmental Sciences, Darling Building, DP418, The University of Adelaide, SA 5005, Australia. Email: john.conran@adelaide.edu.au

² present address: Spinifex Communications, 70 Chalfont St, Salisbury Qld 4107, Australia. Email: julichinchcliffe@bigpond.com

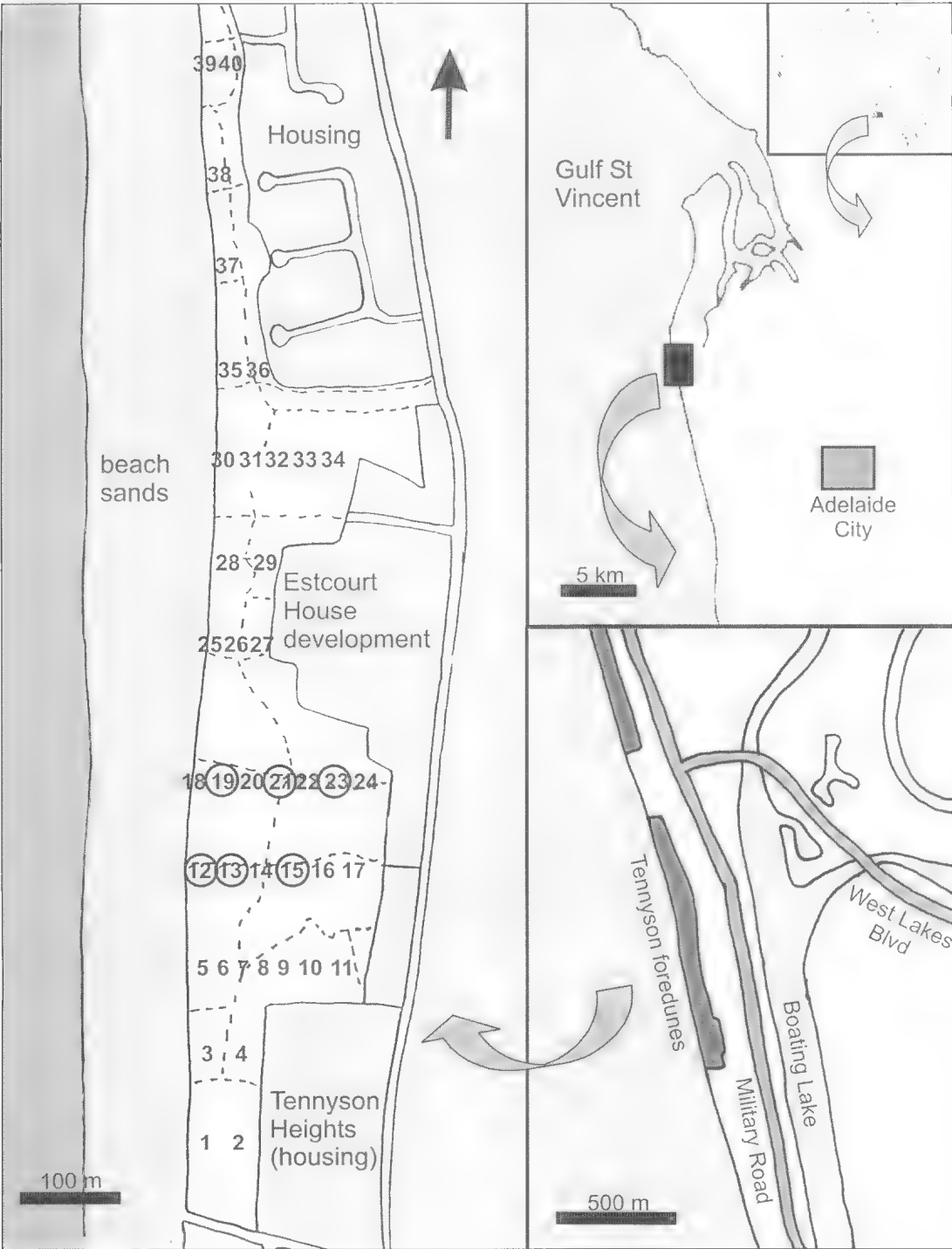


Fig. 1. Map of the Tennyson sand dunes showing the positions of the forty 50 x 2 m sample quadrats. Circled quadrats represent those with no vegetation cover at the time of study.

dune and cliff-top plant communities across South Australia, relating them to ecological gradients and environmental parameters. Similarly, the vegetation of the Murray Mouth and Coorong was studied by Brandle (2002), where 11 floristic groups including several dune associations were recognised. However, although these studies represent invaluable resources for managers at the broader scale, because of the size and complexity of the areas covered, small-scale patterns within particular areas and their local management issues tend to be lost.

The Tennyson sand dunes represent one of the last largely natural dune communities along the Adelaide metropolitan coast, a region where there is considerable effort being expended by local councils and community groups on revegetation for dune stability, habitat for native animals and for shoreline visual amenity (South Australian Coast Protection Board 1993). The dunes were surveyed by Deans *et al.* (1995) and the SA Coast Protection Board (1995), who recorded 39 introduced species, mainly garden escapes (e.g. *Chrysanthemum* spp.), and recent surveys suggested that 57% of the species there are exotics (South Australian Coast Protection Board 2003). Three introduced foredune-building species, *Ammophila arenaria*, *Cakile maritima* and *Elymus farctus*, are regarded as so naturalised as to be beyond control (Heyligers 1985) and the ground-covering exotic African Daisy (*Actotis stoechadifolia*) is considered to suppress regeneration by native species at the site, and to alter dune topography and formation processes (South Australian Coast Protection Board 2003). In contrast, of the 40 native species listed, *Kennedia prostrata* is thought to be locally extinct, *Lomandra leucocephala* subsp. *robusta* is rare to endangered and 11 others were reported as very reduced in the metropolitan area.

However, these descriptions of the dune vegetation along the Adelaide metropolitan coast are mainly qualitative and there are no recent detailed, fine-scale quantitative studies the vegetation patterns in the metropolitan coastal dunes, or elsewhere in the state. Accordingly, our study applies an integrated multivariate numerical approach to one of Adelaide's last remnants of natural dune vegetation in order to provide baseline management information. The major aims of the study were to:

1. Quantify the floristic composition and vegetation patterns of the Tennyson sand dunes.
2. Correlate these patterns to site environmental features.
3. Relate these patterns to the overall health of the ecosystem and its possible long-term management.

Methods

Vegetation patterns

The site consisted of an 11 ha area at Tennyson, near West Beach, 12.5 km NW of Adelaide, South Australia (34° 51' S, 138° 42' E), between Uriah Place and Bournemouth Avenue, representing approximately 1 km of foredunes (Fig. 1) which are subdivided into 18 areas by fenced beach access tracks. Twelve parallel transects were established 100 m apart, perpendicular to the beach and running inland starting 10 m behind the foredune edge. Quadrats were spaced 25 m along each transect, and positioned so that they did not traverse a walkway. The number of quadrats along each transect varied because of the presence of barriers (e.g. Escourt House, car parks etc...), but in total forty 50 x 2 m quadrats were surveyed (Fig. 1). Quadrat size was determined from species area-curve data and guidelines proposed by Kent and Coker (1992) for heterogeneous shrubby heathlands. Within each quadrat, 25 2 x 2 m cells were aligned parallel to the shore, and every species was given an average Braun-Blanquet (1932) cover score based on its cover within each of the 25 cells.

Seven environmental parameters were assessed for each quadrat: distance from the foredune edge (m); topographic position, soil electrical conductivity, pH, surface sand exposure, surface sand disturbance, and litter cover. Topographic position was categorised using a nominal scale adapted from Tongway (1994) as follows: flat (1) lower slope (2) mid-slope- (3) upper slope (4) crest (5). Conductivity and pH were analysed using approximately 10 g of surface sand taken from the centre of each cell and dried at 100°C for 24 h. A 1:5 soil / water suspension was tested using an LC-84 electrical conductivity (EC) meter and a pH meter calibrated to pH 7, and the results averaged for the quadrat. Surface sand exposure (SSE) as the estimated percentage exposed sand in each quadrat, surface sand disturbance (SSD: the estimated percentage of sand showing mechanical disturbance), and litter cover were each measured using a six point scale derived from McDonald *et al.* (1990), ranging from 0 (undisturbed) to 5 (concentrated animal or human activity such as the creation of tracks, vegetation damage, removal or severe trampling).

In addition, the numbers of *Olearia axillaris* plants within each of the three age classes (Juvenile, Mature and Senescent) defined by Hinchliffe and Conran (in press) were recorded within each quadrat to determine whether *Olearia* numbers and life classes correlated with overall site vegetation patterns, and/or with the site environmental parameters.

Data analysis

After exclusion of six quadrats which lacked any vegetation, the quadrat \times species matrix was subjected to cluster analysis by Sørensen association with flexible UPGMA clustering to produce a dendrogram using the program PC-ORD ver. 4.0 (McCune & Mefford 1999). Major divisions in the dendrogram branches were used to define groups. Species which were significantly ($p < 0.05$) associated with the resulting groups, were identified using indicator species analysis (Dufrêne & Legendre 1997), which combines information on species abundance in a particular group and the faithfulness (% indicator value) of occurrence of a species in a particular group and its statistical significance, i.e. utility as a group indicator.

Sites and species were ordinated in PC-ORD 4.0 using non-metric multidimensional scaling (NMS), canonical correspondence analysis (CCA) and principal component analysis (PCA). These different methods, which include both direct (CCA) and indirect (NMS and PCA) gradient analysis techniques, were used to assess the reliability of the resulting groups, i.e. if the same quadrat groups arose despite the analysis they are more likely to represent environmental response groups (Jongman *et al.* 1995). Dendrogram-derived quadrat groups and their indicator species were plotted into the ordination space, allowing the results of the classification and ordination to be viewed simultaneously and as a test of the integrity of the dendrogram groups (Kent & Coker 1992). In addition the correlation between the position of the quadrats on the ordination space and the environmental features recorded for the quadrats was calculated by correlating the scores for the environmental variables against the axis coordinates, plotting the direction of positive correlation as vectors onto the ordination by biplot analysis, where the length of the vector indicates the relative importance of that character in the ordination space (McCune & Mefford 1999).

Results

Fifty-two species were encountered in the 34 quadrats with vegetation cover, of which 30 (58%) were native and 22 (42%) were introduced. The natives with the highest cover were *Olearia axillaris* (present in 30 quadrats) and *Spinifex sericeus* (23), while the dominant introduced species were *Euphorbia paralias* (30 quadrats) and *Lagurus ovatus* (28), reflecting patterns seen elsewhere in South Australian dune systems (Opperman 1999; Brandle 2002). In contrast, other generally common to dominant southern Australian coastal dune species (*sensu* Opperman 1999) such as *Nitraria billardiera*,

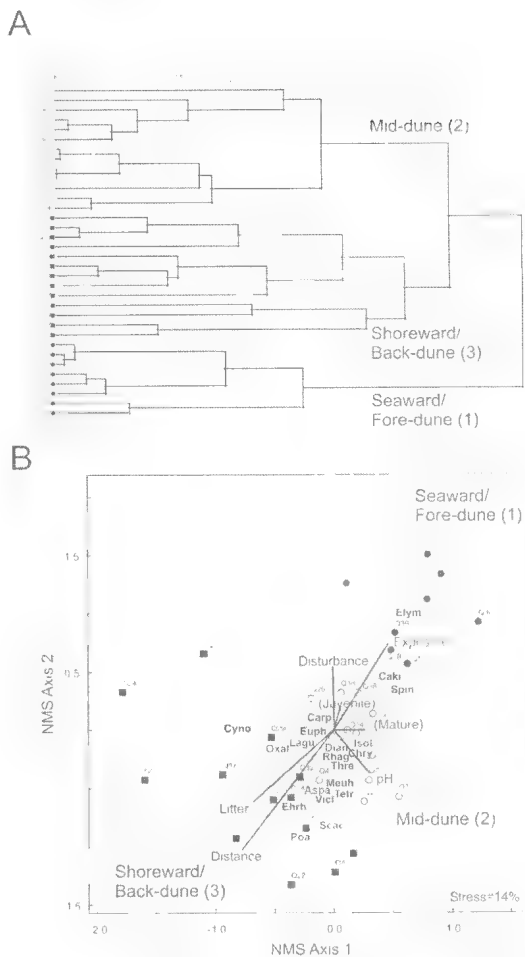


Fig. 2. A: Dendrogram of the quadrats using Sørensen/UPGMA cluster analysis. B: Non-metric Multi-dimensional Scaling analysis (NMS) ordination of the quadrats, and biplot of significant indicator species and correlated environmental parameters. Vector lengths indicate importance and direction of positive increase for feature measured, parameters in parentheses for non-significant trends.

Leucopogon parviflorus and *Senecio lautus* were present in only two three quadrats, as were the locally rare natives *Clematis microphylla* (2 quadrats) and *Pimelia serpyllifolia* (1 quadrat).

Surface sand salinities (NaCl equivalent derived from EC values) were relatively low, averaging 1,220 mgL⁻¹ and ranging from 632 mgL⁻¹ to 2,556 mgL⁻¹.

The dendrogram could be divided into three quadrat clusters (Fig. 2A). Group 1 consisted of eight of the 12 fore-dune quadrats, with *Cakile maritima* and *Elymus farctus* as the significant indicator species (Fig. 3A; Table 1). These quadrats were typically flat, and similar to the Rolling Spinifex/Sea



Fig. 3. A: Seaward/foredune community. B: Mid-dune association. C: Shoreward/backdune community.

Wheat Grass Tussock Grassland of the Coorong dunes (Brandle 2002) and *Elymus*-dominated beach meadow sites reported by Talbot and Talbot (1994).

Group 2 represented 13 sites, most of which were located behind the foredune (Fig. 2A) and represent a mid-dune association (Fig. 3B). There were 9 significant indicator species for Group 2 (Table 1) of which the most strongly significant ($p < 0.01$), and thus most useful as group indicators, were *Threlkeldia diffusa*, *Chrysanthemum coronarium*, *Rhagodia candolleana* ssp. *candolleana*, *Spinifex sericeus* and *Isolepis nodosa*. Group 2 quadrats were also the only ones where the previously common (Cleland 1932) and now locally rare species *Pimelea serpyllifolia* ssp. *serpyllifolia* and *Adriana klotzschli* were recorded.

The remaining 13 quadrats formed Group 3 (Fig. 2A), and were located behind the central walkway and on the west-facing backdune slope (Fig. 3C). There were nine significant indicator species (Table 1), seven of which are introduced weeds, the most significant ($p < 0.01$) being *Ehrharta calycina* and *Oxalis pes-caprae*. Group 3 was also the only area where *Clematis microphylla*, *Calocephalus brownii* and *Melaleuca lanceolata* were observed.

TABLE 1. Significant indicator species, their codes and dendrogram group with which they are significantly associated ($p < 0.05$). Indicator values and probabilities derived using the indicator species analysis method of Dufrène and Legendre (1997). * exotic species. Species nomenclature follows Jessop & Toelken (1986) and Carr & Horsfall (1995).

Species	Code	Group	Indicator value (%)	P
Seaward/Foredune				
* <i>Cakile maritima</i>	CAKI	1	46.2	0.0237
* <i>Elymus farctus</i>	ELYM	1	75.5	0.0001
Mid-dune				
<i>Carpobrotus rossii</i>	CARP	2	44.1	0.0442
* <i>Chrysanthemum coronarium</i>	CHRY	2	65.2	0.0001
<i>Dianella brevicaulis</i>	DIAN	2	42.7	0.0347
* <i>Euphorbia paralias</i>	EUPH	2	46.1	0.0326
<i>Isolepis nodosa</i>	ISOL	2	57.8	0.0026
<i>Mcuhlenbeckea gunnii</i>	MEUH	2	47.6	0.0153
<i>Rhagodia condolleana</i> subsp. <i>candolleana</i>	RIAG	2	56.4	0.0003
<i>Spinifex sericeus</i>	SPIN	2	52.3	0.0006
<i>Threlkeldia diffusa</i>	THRE	2	54.8	0.0001
Shoreward/Backdune				
* <i>Cynodon dactylon</i>	CYNO	3	35.7	0.0211
* <i>Ehrharta calycina</i>	EHRH	3	85.9	0.0001
* <i>Lagurus ovata</i>	LAGU	3	48.2	0.0198
* <i>Asparagus</i> (= <i>Myrsiphyllum</i>) <i>asparagoides</i>	ASPA	3	43.3	0.0299
* <i>Oxalis pes-caprae</i>	OXAL	3	55.6	0.0030
* <i>Poa annua</i>	POA	3	38.5	0.0130
<i>Scaevola crassifolia</i>	SCAE	3	41.0	0.0187
<i>Tetragonia implexicaris</i>	TETR	3	43.6	0.0443
* <i>Vicia monantha</i>	VICI	3	40.7	0.0212

All three of the ordination analyses showed essentially identical results, with the dendrogram groups discrete and arranged as a continuum. Because the patterns were the same, suggesting that the patterns reflect environmental responses, only those for the NMS are presented here (Fig. 2B) as they were both visually clearer than the others, and because NMS is considered to be generally more robust than most other ordination techniques (Minchin 1987). As expected, the significant indicator species for each group plotted into the same ordination space as the group with which they were associated. Correlation of the ordination axes with the environmental data showed that Group 1 was associated with proximity to the shoreward dune edge, high levels of exposed surface sand, low litter levels and a trend towards more numerous *Olearia* Juveniles. Group 2 quadrats were placed centrally in the ordination and were thus intermediate for all of the environmental parameters, although with a trend towards more abundant Mature *Olearia*. Group 3 correlated significantly with distance from the outer dune edge, high litter levels and reduced surface sand exposure, as well as a tendency towards fewer Juvenile *Olearia*. The Group 3 quadrats were also more spread out in the ordination plots, with quadrats dominated by *Poa annua* and *Scaevola*

crassifolia associated with alkaline soils, while those with high cover scores for *Cynodon dactylon*, *Oxalis pes-caprae* and *Lagurus ovatus* located on more acid soils.

Discussion

The complexity of the dune structure in our survey was much lower than that reported by Specht (1972) for the Adelaide region, with many of his association-defining taxa rare or absent from our quadrats, although *Olearia*, *Spinifex*, *Carpobrotus*, *Rhagodia* and *Cakile* were still important. *Olearia* and *Spinifex* were similarly described as common along the dunes between Outer Harbour and Sellick's Beach (Cleland 1932), but in this survey the native perennials *Adriana klotzschli* and *Pimelia serpyllifolia* were also common, whereas these species are now rare. Similarly, Cleland (1932) recorded only 14 introduced taxa between Outer Harbour and Sellick's Beach, compared to the over 40 species now found just at Tennyson.

Elevation and distance are used traditionally to classify coastal vegetation into zones, as both are assumed to reflect maritime influences, particularly exposure to sand abrasion, salt spray or storm waves (Brown & McLachlan 1990; DeOliveira 1994; Talbot & Talbot 1994). At Tennyson, the quadrat

groups also fell along a distance gradient, tending to support this view. However, other studies along the Adelaide coastline considered that species distributions relative to distance from the shore represented successional stages (Specht 1972, 1993, 1997; Specht & Specht 1999), possibly confounding the effects of environment versus time.

Litter cover and vegetation patterns were correlated in our study, and litter is important in succession by modifying dune soils (Specht 1972; Enright 1978). Litter cover increases with successional age (Talbot & Talbot 1994), and at Tennyson, the positive correlation between distance and litter supports this. Higher litter levels towards the back of the dunes can increase soil organics and nutrients (Specht & Specht 1999), but can adversely affect seedling emergence and survival (Facelli & Pickett 1991). The origin (native or exotic) and physical structure of the litter can also affect community composition (Lenz *et al.* 2003). Heavy backdune litter cover from *Ehrharta* and *Lagurus* may help to explain low recruitment by native species in this area, as *Ehrharta* was seen by Hilton & Harvey (2002) to suppress native plant recruitment on the Sir Richard Penin. SA. Nevertheless, correlation alone does not prove that grass litter is necessarily inhibiting native dune species recruitment, as Facelli & Pickett (1991) found that litter may favour establishment in harsh environments by retaining soil moisture and protecting seedlings from desiccation. Specht (1972) also suggested that *Olearia axillaris* seedlings were associated with abundant litter (the opposite of our findings), and *O. polita* in New Zealand showed no spatial relationship between seedling density and litter (Williams & Courtney 1995). Similarly, although not significantly associated with quadrat groups at the site, *Arctotis stoechadifolia* was most abundant in the Group 3 backdune quadrats and is also considered to be a threat to the diversity and regeneration ability of indigenous taxa at Tennyson by its habit of suppressing seedling establishment and growth (South Australian Coast Protection Board 1995).

pH can also affect coastal vegetation (e.g. Specht & Cleland 1961; Chapman 1976; Brown & McLachlan 1990), with higher pH soils on calcareous dunes being more nutrient rich (Specht 1972). In our study, pH correlated with the second CCA Axis and may help to explain the floristic divergence between the quadrats of group III (the backdune), with *Cynodon*, *Oxalis* and *Lagurus*-dominated quadrats correlating with lower pH and those with greater *Poa* and *Scaevola* cover on higher pH soils.

The relatively low surface sand salinities can be explained by rapid leaching of salt spray into the

dunes, particularly once strand vegetation stabilises the sand (Specht 1972; Chapman 1976; Specht & Specht 1999). Low salinities have been reported in North American dunes (Oosting & Billings 1942; Boyce 1954; Barbour *et al.* 1973; Barbour & De Jong 1977), although arid shorelines are often more saline (Johnson 1977; Barbour *et al.* 1985) and closer to those seen at Tennyson. Nevertheless, salinity was not significantly associated with vegetation or other environmental variables in our study, except for pH ($r = 0.51$). Boyce (1954) and Barbour *et al.* (1973) were similarly unable to show correlations between salinity and species distributions, with the latter reporting strong intra-site variation. The pattern may also be affected by seasonality, as salinities would be expected to be higher over the summer and lowest near the end of the winter rains, and this, combined with the timing of germination events may still have an effect on the subsequent vegetation.

There is generally a strong relationship between dune elevation and vegetation (Barbour *et al.* 1973; Nakanishi & Fukumoto 1987; Talbot & Talbot 1994), as it affects the degree to which vegetation is affected by wind, salt spray, soil moisture and nutrients (Carter 1988). Nevertheless, at Tennyson topographic position was not associated with vegetation patterns, raising the question of whether smaller-scale changes in topography might be more important, but these would require sampling at a finer scale.

Disturbed sand did not correlate with any other variable, suggesting that the dunes either show complex disturbance patterns or that disturbance is random. The latter seems unlikely in the light of human trampling patterns (Hylgaard 1980; Degouvenain 1996) and rabbit activity in dunes (Whatmough 1995), but does imply that disturbance does not reflect overall vegetation patterns at the scale sampled. The fact that those quadrats which lacked vegetation were all located close together in the middle of the site suggests that there may be some disturbance-related and/or sample scale effects which require further investigation if that part of the dune is to remain stabilised or to be revegetated successfully.

The species were distributed as a continuum, a phenomenon typical of coastal vegetation both in South Australia (Specht 1972) and more generally (Brown & McLachlan 1990; DeOliveira 1994), and correlated mainly with distance from the shore and litter, agreeing with studies of other dune systems (Talbot & Talbot 1994). Recruitment in the dominant shrub, *Olearia axillaris*, was associated with exposed sands on the seaward foredune, and not with high litter levels (c.f. Specht 1972), and the abundant juvenile plants at the site suggest that the dune vegetation is regenerating.

Nevertheless, the overall dominance of the site by exotic taxa and the possibility for future spread by more aggressive, potentially regeneration-preventing species, particularly in the backdune, suggests that overall site health is not optimum. Similarly, there were considerable numbers of dead shrubs, including *Olearia* across the site, and although recruitment was evident, the presence of dead shrubs in the "empty" quadrats implies that regeneration is not uniform.

Placing these results in a management context, some caution is required since the patterns recovered are scale-dependant. The Tennyson dunes contain more than 80 plant species, ranging from grasses and herbs through to tall shrubs (Deans *et al.* 1995), and the distribution and abundance of these species will vary at different sampling scales. This has practical implications, particularly if the same types of patterns are to be reproduced from survey data gathered in other manners or at different scales. Specht (1972) recognised six different vegetation associations for Adelaide dune systems over the same general distance from the shore as our study, implying that finer-scale sampling may reveal more localised patterning, although many of the key species for his zones were also significant indicator species within our study. In contrast, Opperman's (1999) *Olearia/Rhagodia* shrubland was similar to our mid-dune association, but our fore- and backdune associations appear to be too dominated/degraded by weeds to fit easily into either Specht's (1972), Opperman's (1999) or Brandle's (2002) vegetation classes.

A major problem identified in this study was the dominance of introduced species. This dominance by exotic taxa indicates that the dunes are not comparable to natural systems and that management practices to encourage the reestablishment of more native taxa and to limit or reduce weeds across the site need to be implemented. The extent and potential for future spread by *Elymus*, *Ehrharta* and *Arctotis* are causes for concern, as are the reasons for the

absence of native seedlings toward the backdunes. Furthermore, because sampling commenced 10 metres back from the foredune edge, but *Elymus* is considered to be most abundant just above the high tide mark or strandline (Heyligers 1985), its abundance at Tennyson, particularly in relation to *Spinifex*, may have been underestimated. It is also possible that the relative abundance of introduced species has been underestimated by the present survey, as the data were collected mainly across winter and exotic spring annuals or late-emerging geophytic weeds may have been missed.

These findings provide baseline information about the structure and status of the dune vegetation at Tennyson from which strategies for more effective ongoing dune stabilisation can be developed. The management of weeds, key species and rare or locally endangered species at the site represent priority areas for further research. In particular, the role of disturbance, both natural and human on the biology and recruitment of the various weeds as well as the natives is essential if the dunes are to be managed successfully in the long term.

Acknowledgements

The study was part of an Honours degree by JH within the Department of Botany (now Discipline of Environmental Biology), School of Earth and Environmental Sciences, The University of Adelaide, who are thanked for the provision of resources. The Coastal Management Section of the Department of Environment and Natural Resources and the Hindmarsh Woodville Council are thanked for permission to undertake the research in the foreshore areas under their control. Ron Sandercock from DENR and the Tennyson Dunes Group are thanked for their ongoing support of the project and provision of resources and local expertise. Dr José Facelli is thanked for comments on the manuscript.

References

- BARBOUR, M. G., CRAIG, R. B., DRYSDALE, F. R. & GHISELIN, M. T. (1973) "Coastal Ecology: Bodega Head" (University of California Press, Berkeley, CA).
- & DE JONG, T. M. (1977) Response of west coast beach taxa to salt spray, seawater inundation and soil salinity. *Bull. Torrey Bot. Club* **104**, 29-34.
- & PAVLIK, B. M. (1985) Marine beach and dune plant communities pp. 298-322. In Chabot, B. F. & Mooney, H. A. (Eds) "Physiological Ecology of North American Plant Communities" (London, Chapman and Hall).
- BIRD, E. C. & JONES, D. J. B. (1988) The origins of foredunes on the coast of Victoria, Australia. *J. Coastal Res.* **4**, 181-192.
- BOYCE, S. G. (1954) The salt spray community. *Ecol. Monogr.* **24**, 29-67.
- BRANDLE, R., Ed. (2002) "A Biological Survey of the Murray Mouth Reserves, South Australia" (Biodiversity Survey and Monitoring, National Parks and Wildlife, South Australia, Department of Environment and Heritage, Adelaide).
- BRAUN-BLANQUET, J. (1932) "Plant Sociology" (McGraw-Hill, New York).
- BROWN, A. C. & McLACHLAN, A. (1990) "Ecology of Sandy Shores" (Elsevier, Amsterdam).
- CARR, G. W. & HORSFALL, P. F. (1995) Studies in Phormiaceae (Liliaceae) I. New species and combinations in *Dianella* Lam. ex Juss. *Muelleria* **8**, 365-378.
- CARTER, R. W. G. (1988) "Coastal Environments. An introduction to the physical, ecological and cultural system of coastlines" (Harcourt Brace Jovanovich, London).

- CHAPMAN, V. J. (1976) "Coastal Vegetation, 2nd Edition" (Pergamon Press, Oxford).
- CLELAND, M. D. (1932) The flora between Outer Harbour and Sellick's beach, South Australia. *S. Aust. Nat.* **14**, 45-133.
- DEANS, J. A., FOTHERINGHAM, D. G. & WYNNE, A. A. (1995) "Semaphore Park and Tennyson Foreshore: Options for Protection" (South Australian Coast Protection Board Technical Report No. 94/2, Adelaide).
- DEGOUVENAIN, R. C. (1996) Indirect impacts of soil trampling on tree growth and plant succession in the North Cascade Mountains of Washington. *Biol. Cons.* **75**, 279-287.
- DEOLIVEIRA, F. A. T. (1994) Gradient analysis of an area of coastal vegetation in the state of Paraíba, Northeastern Brazil. *Edinb. J. bot.* **50**, 217-236.
- DUFRÈNE, M. & LEGENDRE, P. (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecol. Monogr.* **67**, 345-366.
- ENRIGHT, N. J. (1978) The interrelationships between plant species distribution and properties of soils undergoing podsolization in a coastal area of South Western Australia. *Austral. J. Ecol.* **3**, 389-401.
- FACELLI, J. M. & PICKETT, S. T. A. (1991) Plant litter: its dynamics and effects on plant community structure. *Bot. Rev.* **57**, 1-32.
- FENNER, C. & CLELAND, J. B. (1932) The geography and botany of the Adelaide coast. *S. Aust. Nat.* **14**, 45-48, 55-56, 109-20, 128-33.
- GRAY, A. J. (1985) Adaptation in perennial coastal plants with particular reference to heritable variation in *Puccinellia maritima* and *Ammophila arenaria*. *Vegetatio* **61**, 179-188.
- HARTY, R. L. & McDONALD, T. J. (1973) Germination behaviour in beach *Spinifex* (*Spinifex hirsutus* Labill.). *Australian Journal of Botany* **20**, 241-251.
- HESP, P. A. (1984) Foredune formation in southeastern Australia pp. 69-97 In Thom, B. G. (Ed.) "Coastal Geomorphology in Australia" (Academic Press, Sydney).
- HEYLIGERS, P. C. (1984) Beach invaders: sea rockets and beach daisies thrive. *Austral. Nat. Hist.* **21**, 212-214.
- (1985) The impact of introduced plants of foredune formation in south-eastern Australia. *Proc. Ecol. Soc. Aust.* **14**, 1-23.
- HILTON, M. & HARVEY, N. (2002) Management implications of exotic dune grasses on the Sir Richard Peninsula, South Australia pp. 186-189 In "Coast to Coast 2002 Conference Proceedings" (Coastal CRC, Tweed Heads, NSW).
- HINCHLIFFE, J. & CONRAN, J. G. (in press) Life history classes in Coast Daisy-bush (*Olearia axillaris*: Asteraceae) as a possible means of monitoring coastal dunes. *Austral. J. Bot.* (In press).
- HYLGAARD, T. (1980) Recovery of plant communities on coastal sand-dunes disturbed by human trampling. *Biol. Cons.* **19**, 15-25.
- JESSOP, J. P. & TOELKEN, H. R., Eds (1986) "Flora of South Australia" (South Australian Government Printer, Adelaide).
- JOHNSON, A. F. (1977) A survey of the strand and dune vegetation along the Pacific and southern gulf coasts of Baja California, Mexico. *J. Biogeog.* **7**, 83-99.
- JONGMAN, R. H. G., TER BRAAK, C. J. F. & VAN TONGEREN, O. F. R., Eds (1995) "Data analysis in community and landscape ecology" (Cambridge University Press, Cambridge).
- KENT, M. & COKER, P. (1992) "Vegetation Description and Analysis. A Practical Approach" (Belhaven Press, London).
- LENZ, T. I., MOYLE-CROFT, J. L. & FACELLI, J. M. (2003) Direct and indirect effects of exotic annual grasses on species composition of a South Australian grassland. *Austral. Ecol.* **28**, 23-32.
- MCCUNE, B. & MEFFORD, M. J. (1999) "PC-ORD. Multivariate Analysis of Ecological Data, Version 4." (MjM Software Design, Gleneden Beach, Oregon, USA).
- McDONALD, R. C., ISBELL, R. F. & SPEIGHT, J. G., Eds (1990) "Australian Soil and Land Survey Field Handbook (2nd edition)" (Inkata Press, Melbourne).
- MINCHIN, P. R. (1987) An evaluation of the relative robustness of techniques for ecological ordination. *Vegetatio* **69**, 89-107.
- MORCOM, N. F. (2002) Approaches for integrating coastal management in South Australia pp. 299-302 In "Coast to Coast 2002 Conference Proceedings" (Coastal CRC, Tweed Heads, NSW).
- & HARVEY, N. (2002) South Australian coastal planning: protection or integration? *Australian Planner* **39**, 19-24.
- NAKANISHI, H. & FUKUMOTO, H. (1987) Coastal vegetation and topography in northern Hokkaido, Japan. *Hikobia* **10**, 1-12.
- OLSON, J. S. (1958) Rates of succession and soil changes on southern Lake Michigan sand dunes. *Bot. Gaz.* **119**, 125-170.
- OOSTING, H. J. & BILLINGS, W. D. (1942) Factors affecting vegetational zonation on coastal dunes. *Ecology* **23**, 131-142.
- OPPERMAN, A. (1999) "A Biological Survey of the South Australian Coastal Dune and Cliff-top Vegetation." (Coast and Marine Section, Environmental Protection Agency, Department for Environment, Heritage and Aboriginal Affairs, South Australia, Adelaide).
- OSBORN, T. G. B. (1914) Sketches of vegetation at home and abroad. III. Notes on the flora around Adelaide. *South Australia. New Phytol.* **13**, 109-121.
- PARTRIDGE, T. R. (1992) Vegetation recovery following sand mining on coastal dunes at Kaitorete Spit, Canterbury, New Zealand. *Biol. Cons.* **61**, 59-71.
- ROZEMA, J., BIJWAARD, P. & BROEKMAN, R. (1985) Ecophysiological adaptations of coastal halophytes from foredune and salt marshes. *Vegetatio* **62**, 499-521.
- SOUTH AUSTRALIAN COAST PROTECTION BOARD (1993) The Adelaide Metropolitan Coastline. *Coastline* **27**, 1-7.
- (1995) "Coastal Landcare Manual" (DEHAA, Adelaide).
- (2003) Garden plants that are known to become serious coastal weeds. *Coastline* **34**, 1-16.
- SPECHT, R. L. (1972) "The Vegetation of South Australia, 2nd Edition" (Government Printer, Adelaide).
- (1993) Dry coastal ecosystems of Australia - an overview of the dune vegetation pp. 223-237 In van der Maarel, E. (Ed.) "Ecosystems of the World. Vol. 2B. Dry Coastal Ecosystems: Africa, America, Asia and Oceania" (Elsevier, Amsterdam).
- (1997) Ecosystem dynamics in coastal dunes of eastern Australia pp. 483-495 In van der Maarel, E. (Ed.) "Ecosystems of the World, Vol. 2C. Dry Coastal Ecosystems: General Aspects" (Elsevier, Amsterdam).
- & Cleland, J. B. (1961) Flora conservation in South Australia. I. The preservation of plant formations and associations recorded in South Australia. *Trans. R. Soc. S. Aust.* **85**, 177-196.
- & SPECHT, A. (1999) "Australian Plant Communities" (Oxford University Press, Oxford).
- TALBOT, S. S. & TALBOT, S. L. (1994) Numerical classification of the coastal vegetation of Attu Island, Aleutian Islands, Alaska. *J. Veg. Sci.* **5**, 867-876.
- VILES, H. & SPENCER, T. (1995) "Coastal Problems: Geomorphology, Ecology and Society at the Coast" (Edward Arnold, London).

- WALKER, J., THOMPSON, C. H., FERGUS, I. F. & TUNSTALL (1981) Plant succession and soil development in coastal sand dunes of subtropical eastern Australia pp. 107-131. In Shugart, H. H., Botkin, D. & West, D. (Eds) "Forest succession: concepts and applications" (Springer, New York).
- WARMING, E. (1891) De psammophile vormationer i Danmark. *Vid. Medd. Natur. For. Kjøbenhavn* **1891**, 153.
- WHATMOUGH, J. A. (1995) Grazing on sand dunes: the reintroduction of the rabbit *Oryctolagus cuniculus* L. to Murlough NNR, Co. Down. *Linn. Soc. Lond.* **56** (Supplement), 39-43.
- WILLIAMS, P. A. & COURTNEY, S. P. (1995) Site characteristics and population structures of the endangered shrub *Olearia polita* (Wilson et Garnock-Jones), Nelson, New Zealand. *N.Z. J. Bot.* **33**, 237-241.

**REPRODUCTION OF COMMON CARP IN SOUTH AUSTRALIA,
SHOWN BY YOUNG-OF-THE-YEAR SAMPLES,
GONADOSOMATIC INDEX AND THE HISTOLOGICAL
STAGING OF OVARIES**

BY B. B. SMITH†‡ & K. F. WALKER**

Summary

Smith, B. B. & Walker, K. F. (2004) Reproduction of common carp in South Australia, shown by young-of-the-year samples, gonadosomatic index and the histological staging of ovaries. Trans. R. Soc. S. Aust. 128(2), 249-257, 30 November, 2004.

Young-of-the-year (YOY) samples, gonadosomatic index (GSI) and the histological staging of ovaries were used to monitor the reproduction of common carp (*Cyprinus carpio* L.) in the lower River Murray, South Australia, from August 2001 to December 2002. Spawning occurred initially over 9 months from late September 2001 to May 2002, the longest period recorded in Australia.

Key Words: Cyprinidae, Murray-Darling Basin, Australia, aging, cohorts, hatch dates, GSI, spawning.

REPRODUCTION OF COMMON CARP IN SOUTH AUSTRALIA, SHOWN BY YOUNG-OF-THE-YEAR SAMPLES, GONADOSOMATIC INDEX AND THE HISTOLOGICAL STAGING OF OVARIES

by B. B. SMITH*^{†‡} & K. F. WALKER*

Summary

SMITH, B.B. & WALKER, K. F. (2004) Reproduction of common carp in South Australia, shown by young-of-the-year samples, gonadosomatic index and the histological staging of ovaries. *Trans. R. Soc. S. Aust.* 128(2), 249-257, 30 November, 2004.

Young-of-the-year (YOY) samples, gonadosomatic index (GSI) and the histological staging of ovaries were used to monitor the reproduction of common carp (*Cyprinus carpio* L.) in the lower River Murray, South Australia, from August 2001 to December 2002. Spawning occurred initially over 9 months from late September 2001 to May 2002, the longest period recorded in Australia. It recommenced in September 2002 and continued until at least December, when sampling ended. Contrary to previous reports, hatch-dates estimated from otolith analyses revealed that in each year, spawning was continuous from onset until completion, and that there were two peaks in YOY production between mid-October and December 2001 and mid-January and mid-March 2002. Over the entire period, there were at least 29 discrete spawning events at two locations about 30 river-km apart, most of them synchronous. GSI and histological evidence indicated spawning over seven months, including two months where the hatch-date data failed to identify any reproductive activity. Thus, the benefits of combining analyses of YOY and ovary samples are apparent here, where reproduction is protracted and there is potentially low YOY survivorship in some months, and where the local ecology of the target species is not well-understood.

KEY WORDS: Cyprinidae, Murray-Darling Basin, Australia, aging, cohorts, hatch dates, GSI, spawning.

Introduction

Studies of teleost reproduction employ two basic approaches. One monitors changes in sex steroid levels and/or the ovarian condition of mature fish via the gonadosomatic index (GSI) and macroscopic and histological staging. The other utilizes length-frequency distributions for cohorts and hatch- and spawning-date distributions estimated from otoliths, scales or other bony structures, derived from regular samples of young-of-the-year (YOY) fish. The two approaches are complementary. For example, gonad staging reveals recent or imminent spawning, but does not indicate the survivorship of the early life stages. On the other hand, YOY samples do indicate survivorship but not unsuccessful spawning due to infertility, fungal infection, starvation, predation or other environmental factors (Humphries and Lake

2000). Ideally, both approaches should be combined (Pinsent and Methven 1997), but this is uncommon in practice (e.g. Spranza and Stanley 2000).

In Australia, published studies of reproduction in common carp (Cyprinidae: *Cyprinus carpio* L.) have produced incongruent results: YOY samples imply infrequent spawning over 2-4 months annually (Vilizzi 1998; Hume *et al.* 1983¹; Stuart and Jones 2002²), whereas staging of gonads indicates regular spawning over 6-7 months (Sivikumaran *et al.* 2003; Smith and Walker 2004). The disparity could reflect local variations in climate, but could also reflect the shortcomings of unilateral approaches to sampling and analysis.

In this paper, part of an ongoing study (Smith and Walker 2003a, 2003b, 2004), we draw upon YOY samples and histological information to describe the reproductive biology of carp in the River Murray, South Australia. In this region, carp became a major pest following their introduction from Germany in the 1960s (e.g. Koehn *et al.* 2000).

Materials and Methods

Field sampling

YOY sampling occurred every 4-6 weeks over 17 months (1 August 2001 to 31 December 2002) in backwaters at Punyelroo and Walker Flat ('Walker Flat South') on the River Murray downstream of Blanchetown (Weir 1), South Australia. At each location, six 20 m hauls of a seine net (5 x 1.5 m x 6 mm stretched mesh, 1.2 m cod-end) were made in

* Cooperative Research Centre for Freshwater Ecology, School of Earth and Environmental Sciences, The University of Adelaide, Adelaide, South Australia 5005.

[†] Current address: Cooperative Research Centre for Pest Animal Control, SARDI Aquatic Sciences - Inland Waters, GPO Box 120, Henley Beach, South Australia 5022.

[‡] Correspondence: Tel. +61 8 8207 5329; Fax +61 8 8207 5481; Email: smith.ben2@saugov.sa.gov.au

¹ Hume, D. J., Fletcher, A. R. & Morison, A. K. 1983. Carp Program. Final Report. Arthur Rylah Institute for Environmental Research, Fisheries & Wildlife Division, Ministry for Conservation, Heidelberg, Victoria. Unpublished, 214 p.

² Stuart, I. & Jones, M. 2002. Ecology and management of common carp in the Barmah-Millewa Forest. Final Report of the Point Source Management of Carp Project to Agriculture, Fisheries & Forestry Australia. Arthur Rylah Institute for Environmental Research, Heidelberg, Victoria. Unpublished, 214 p.

likely nursery areas (water <60 cm depth, with abundant submerged vegetation: Sigler 1958; Smith 2004³). This net was selective toward small fish (95% were between 10–45 mm SL; West and King 1996), but, as carp in this region attain 45 mm standard length (SL) about 6 weeks after hatching (Vilizzi 1998), the 4–6 week sampling interval was presumed to reveal all successful spawning events. Thus, carp of 10–45 mm SL were retained for analysis, and this also covered the size-range that is suitable for age estimation via the enumeration of daily otolith increments (Vilizzi 1998). If no YOY carp were captured in six hauls, sampling was abandoned; otherwise, it continued either until 50 fish had been obtained or 3 hours had elapsed. In total, 713 YOY carp were collected and samples were preserved in 70% ethanol (after Smith and Walker 2003a).

Laboratory analysis

All YOY carp were weighed using a digital scale (0.0001 g) after draining the mouth and gill cavities and blotting with absorbent paper (Treasurer 1992), and length (SL, 0.01 mm) was measured using digital calipers under a magnifying lamp. Subsequently, to correct for body shrinkage that occurs in alcohol, pre-calibrated regression equations were used to estimate 'initial' (pre-preservation) lengths and weights from those measurements made after preservation (Smith and Walker 2003a).

Where possible, both the left and right otoliths (lapilli) were removed from each fish and mounted on microscope slides using Crystalbond[®] thermoplastic cement, and the one with the most distinct growth increments (validated as daily by Vilizzi 1998; Smith and Walker 2003b) was selected for processing and age estimation (post-hatch ages). To do this, lapilli were ground in the sagittal plane to thin-sections using a variable speed Gemmasta[®] 8" lapping machine with 12 µm diamond polishing discs, and daily growth increments were enumerated under a 100–400x compound microscope linked to a high-resolution monitor. Two 'blind' counts were made (without knowledge of length/weight) and if there was any discrepancy between the age estimates, a third and final count was made. The final age estimate (in days) was reduced by -1 to account for there being, on average, one increment present at the time of hatching (Smith and Walker 2003b). In total, age estimates were made for 575 YOY carp. The remaining 138 fish were disregarded because

both otoliths were lost ($n = 21$) or rendered unusable in processing (over-grinding or cracking, $n = 55$), or had indistinct increments ($n = 62$).

Estimated hatch-dates were calculated for each fish by subtracting the final age estimate from the date of capture (Equation 1), and hatch-date distributions were plotted separately for each backwater (Figs. 1a–b) and for the pooled data (Fig. 1c).

Equation 1

$$\text{Hatch date} = \text{date of capture} - \text{final age estimate}$$

Mean growth rates were also calculated for each fish (Equation 2). In this case, the mean length at hatch (5 mm TL) was subtracted from the 'initial' (pre-preservation) length at capture because only the post-hatch age was calculated, and all YOY carp are c. 5 mm TL at hatching (Alikunhi 1966). If this was ignored, growth rate estimates would have been exaggerated, particularly with respect to very small/young fish (Smith 2004³).

Equation 2

$$\text{Mean growth rate} \left(\frac{\text{mm} \cdot \text{d}^{-1}}{\text{mm}} \right) = \frac{(\text{'initial' length at capture} - \text{mean length at hatch})}{\text{final age estimate}}$$

Smith and Walker (2004) provide complementary information about the calculation of gonadosomatic index (GSI, equation 3) and the histological staging of ovaries, and include photographs and descriptions of each reproductive stage. Briefly, via observations of oocytes stages (named 'whole-section inspection') and inspections for migratory nuclei and post-ovulatory follicles, the ovaries of 111 female carp were histologically classified into one of six developmental stages: immature, early-developing, late-developing, ripe, spent and regressing. Ripe and spent ovaries were indicative of imminent or recent spawning, respectively.

Mature females were sampled from November 2001 to October 2002.

Equation 3

$$\text{Gonadosomatic index (GSI)} = \frac{\text{gonad mass}}{\text{total body mass}} \times 100\%$$

Results

The mean length and weight of the 575 fish for which an age estimate was made were, 22.7 mm SL (± 6.3 S.D.; range 10.2–39.9 mm) and 0.43 g (± 0.38 , 0.017–2.13 g), respectively, and their mean estimated age and growth rate were 39.4 days

³ Smith, B. B. 2004. The state of the art: a synopsis of information on carp in Australia. South Australian Research and Development Institute, Primary Industries and Resources South Australia, Adelaide. Unpublished Technical Report, 70 p.

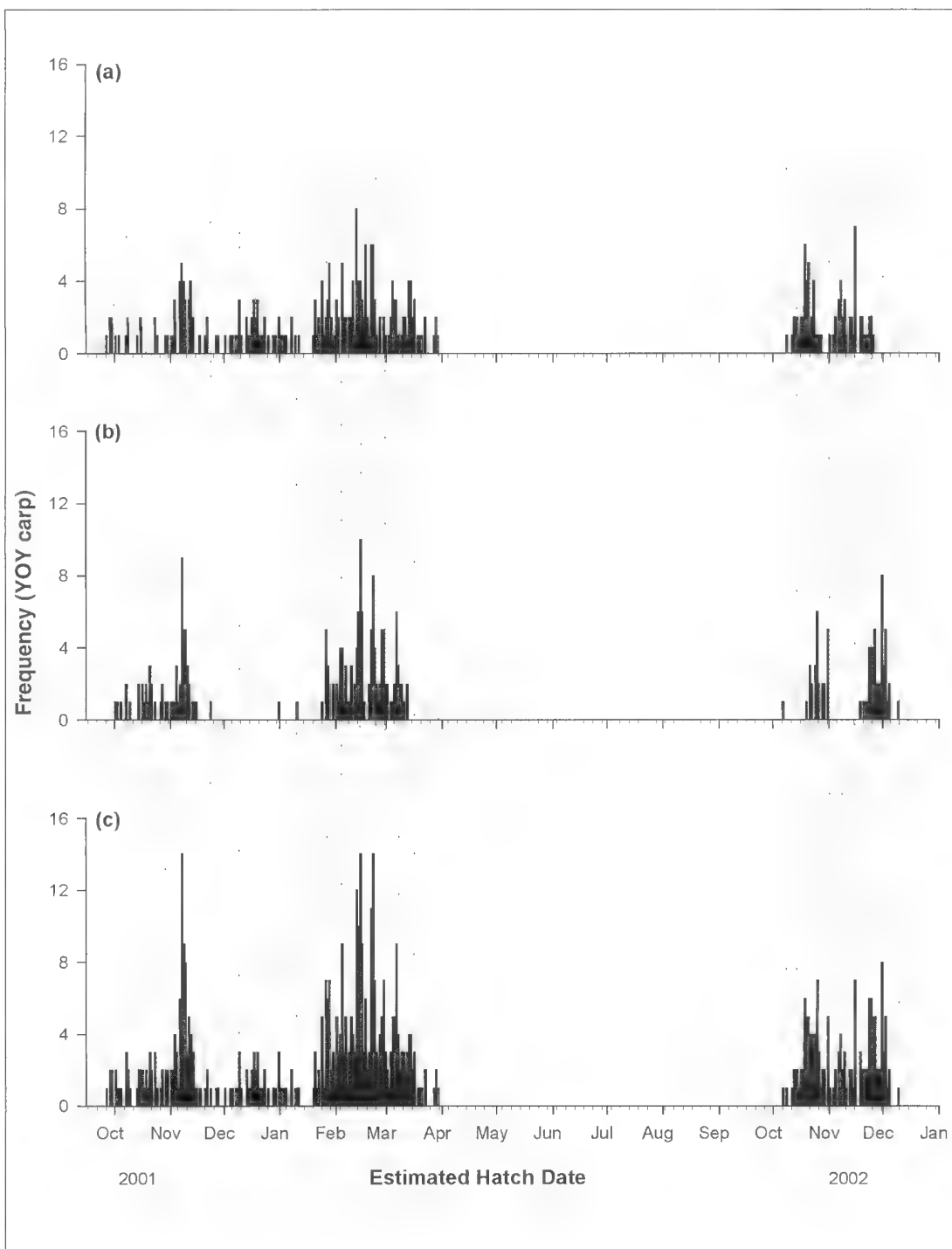


Fig. 1. Estimated hatch-date distributions of YOY carp sampled every 4-6 weeks from August 2001 to December 2002 at (a) Walker Flat South ($n = 317$), (b) Punyelroo ($n = 258$) and (c) Walker Flat South and Punyelroo combined ($n = 575$). No sampled fish were estimated to have hatched prior to 27 September 2001 or between 27 March and 4 October 2002. Minor ticks on abscissa are at 5-d intervals.

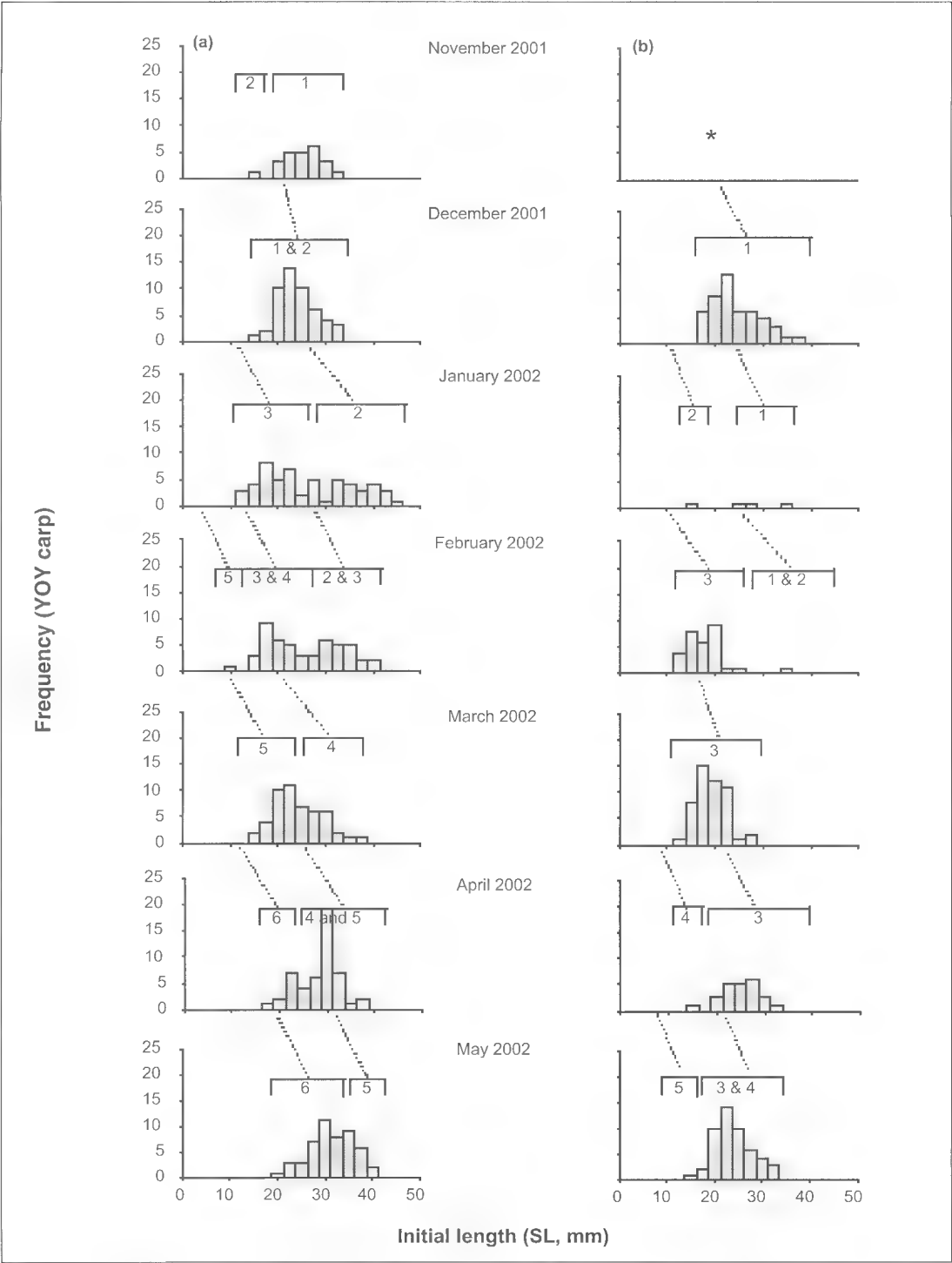


Fig. 2. Modal progression of length frequencies of YOY carp sampled monthly from August 2001 to July 2002 at (a) Walker Flat South and (b) Punyelroo (*length and weight measurements precluded as fish were not preserved live on capture).

(± 15.4 , 12–94 d) and $0.5 \text{ mm}\cdot\text{d}^{-1}$ (± 0.12 , 0.22–1.25 $\text{mm}\cdot\text{d}^{-1}$), respectively. Seine net catches were consistent at Walker Flat South, where beds of ribbon weed (*Vallisneria americana*) provide year round habitat. At Punyelroo, however, few YOY carp ($n < 5$) were sampled in January and May 2002, when most submerged vegetation was exposed by low water levels (Table 1).

The precision of estimates, indicated by the Index of Average Percent Error (IAPE = 2.08%: Beamish and Fournier 1981) and the Coefficient of Variation

(CV = 2.94%: Chang 1982), exceeded the 95% target suggested by Campana (2001). Subjectively, 50 percent of estimated ages were considered to be within ± 1 –2 d of the true age, and the remainder within ± 3 d.

Cohort analyses

Cohort analyses (after Brown *et al.* 2004) indicate that 5–6 primary cohorts of YOY carp were spawned in 2001–2002 at both Walker Flat South and Punyelroo (Fig. 2). One and three cohorts, respectively, are apparent in data for the same localities in November and December 2002 (Fig. 3).

Hatch-date distributions

Figures 1a–c show estimated hatch-dates for YOY carp from August 2001 to December 2002. YOY carp hatched over at least 7 months, from late September 2001 to late March 2002, but not from April to September 2002. Hatching subsequently began in early October 2002, at the start of the 2002–2003 season. Spawning was continuous, from onset to completion, at each location. Successful reproductive events lasted 2–10 days and were separated by periods of up to 2 weeks. Over the entire period, 29 successful events were apparent, 20 of them synchronous at the two locations. The distributions for each location are visually similar,

TABLE 1. Numbers of YOY carp per sample at Punyelroo and Walker Flat South from August 2001 to December 2002. No YOY carp were sampled between August 2001 and October 2001 or June 2002 and October 2002.

Date	Punyelroo	Walker Flat South	Total
17 Nov 01	28	24	52
16 Dec 01	50	50	100
19 Jan 02	4	50	54
26 Feb 02	30	50	80
20 Mar 02	50	50	100
16 Apr 02	49	49	98
25 May 02	2	50	52
13 Nov 02	27	50	77
23 Dec 02	50	50	100
	Grand Total		713

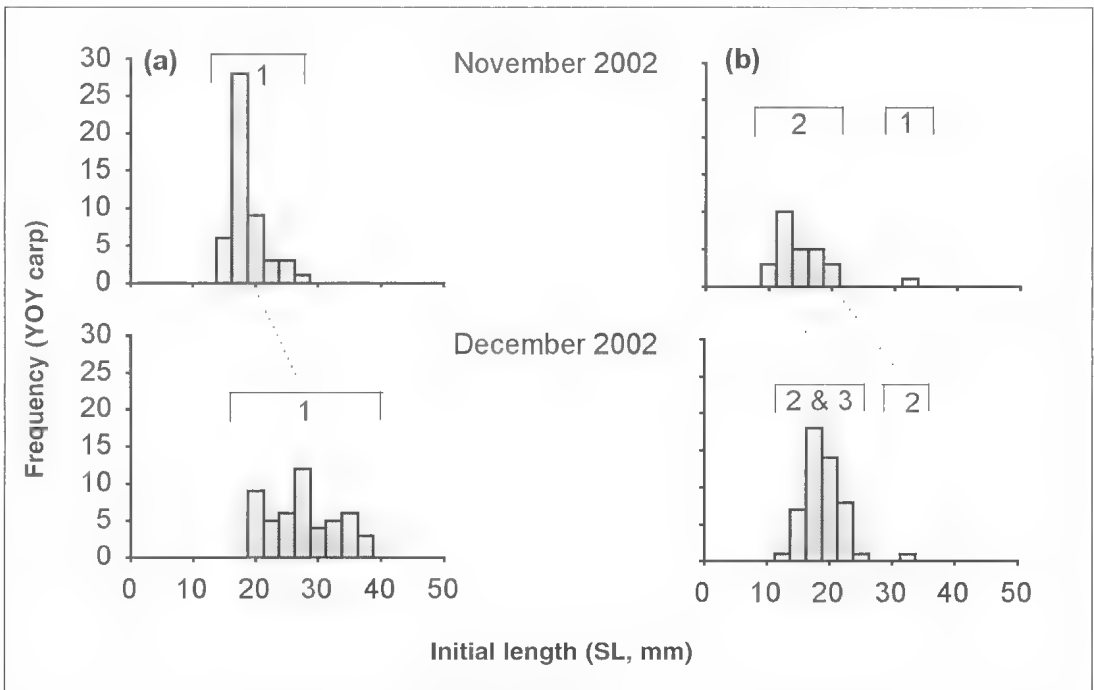


Fig. 3. Modal progression of length frequencies of YOY carp sampled monthly from August 2002 to December 2002 at (a) Walker Flat South and (b) Punyelroo.

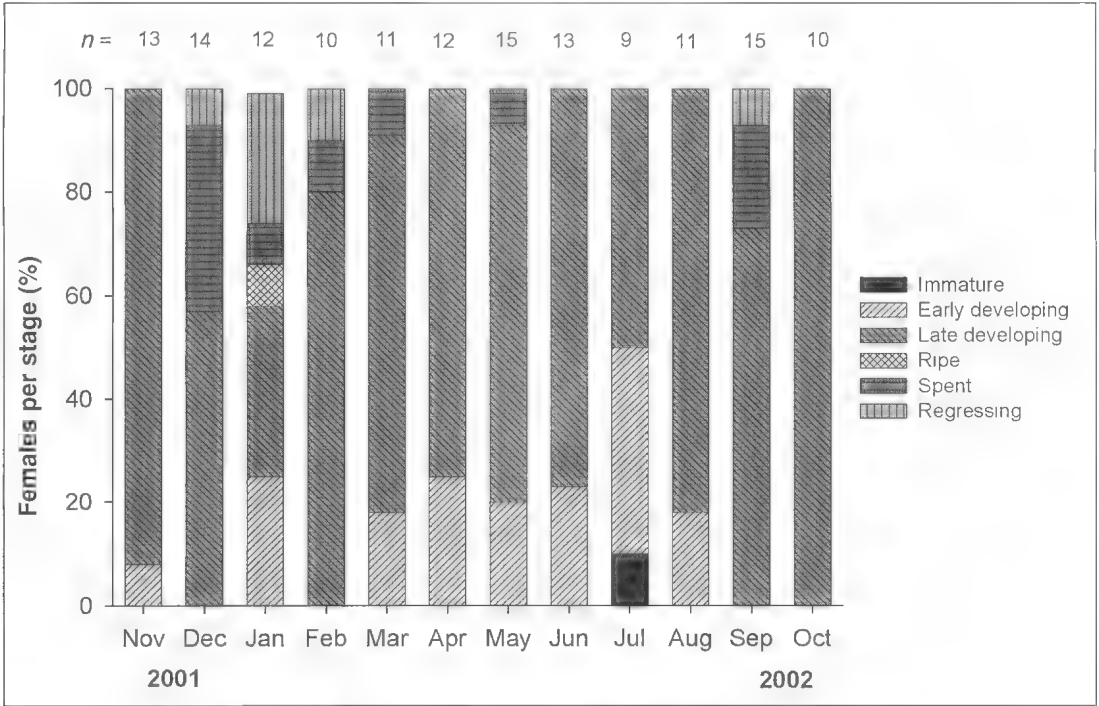


Fig. 4. Relative numbers of female carp at each reproductive stage at the two sample locations, November 2001 to October 2002.

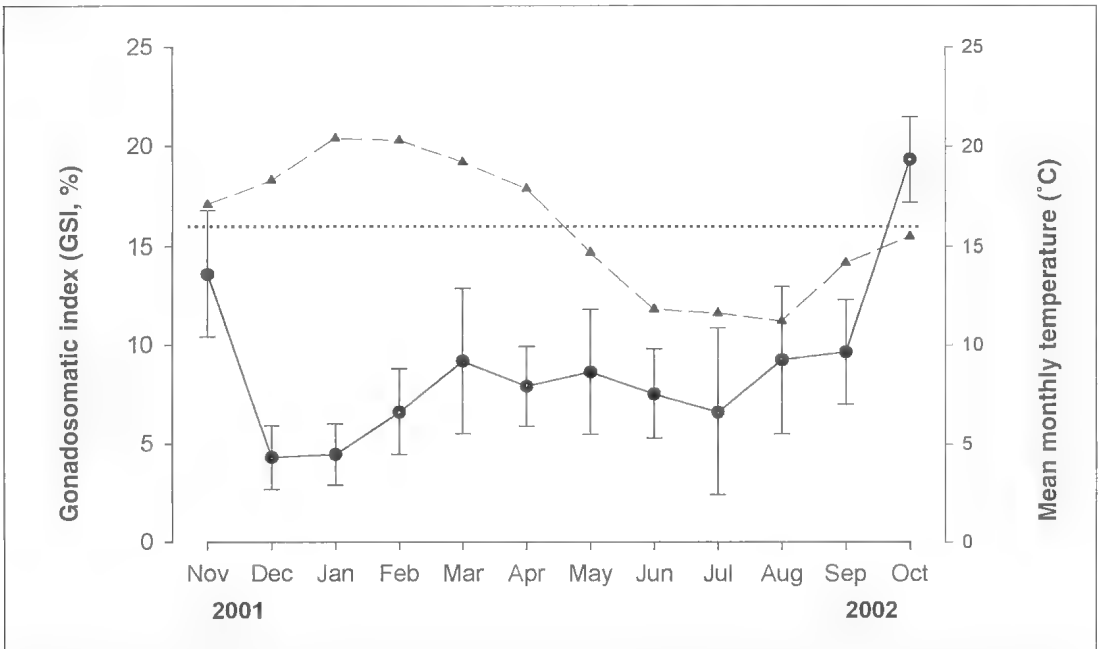


Fig. 5. Monthly changes in gonadosomatic index (GSI) for female carp at the two sample locations, November 2001 to October 2002. Females: ●, solid line; Mean monthly temperature: ▲, dashed line; Approximate lower temperature limit for carp spawning (16°C), dotted line. Standard error bars included.

TABLE 2. Comparative evidence of spawning from gonad staging (GSI, ovary histology) and YOY samples (hatch-date distributions from otolith age estimates). ?: no mature females sampled.

	2001					Evidence of Spawning												2002		
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
GSI	?	?	?	\				\		✓					✓	?	?			
Female histology	?	?	?		✓	✓	\	\		✓				✓		?	?			
YOY sampling		✓	✓	✓	✓	✓	\	\							✓	✓	\			

and indicate that most surviving YOY carp arose from spawning events in November 2001, mid-January to late March 2002, and mid-October 2002 to at least early December 2002.

Histological analyses and GSI

Histological staging also indicated protracted spawning during 2001-2002. 'Spent' fish were observed in December, January (+1 fish classified as 'ripe'), February, March and May. Later, spent fish were present in September, at the onset of spawning for 2002-2003 (Fig. 4). Thus, histological evidence suggests that spawning occurred initially over at least 6 months, from mid-December to mid-May in 2001-2002, and began again in mid-September 2002. There are no histological data for August, September and October 2001 or November and December 2002, as no mature fish were captured in these periods. Peaks in GSI (0.5-24.8%) occurred in November 2001 and October 2002, and lesser peaks in March and May 2001, suggesting that there was also spawning at these times (Fig. 5).

Comparison of methods

Table 2 compares the results of YOY samples and gonad staging (GSI, ovary histology), indicating months where there was evidence of spawning. Thus, spawning occurred in 13 of 17 months of observation, from September 2001 to May 2002 (9 months) and from September 2002 until at least December 2002 (4 months), when sampling ended. However, there is limited concordance between the two classes of methods. For example, in May and September 2002, histological examination of ovaries indicate some spawning, although no YOY carp were estimated to have hatched then. In November 2001 and October 2002, when many YOY carp were estimated to have hatched, there was no histological evidence of spawning.

Discussion

Carp spawn in well-vegetated, slow-flowing or still water, when mean water temperatures exceed 15-16°C for >2-4 weeks (Swee and McCrimmon 1966; Crivelli 1981; Davies and Hanyu 1986; Brzuska 1989; Guha and Mukherjee 1991; Smith and Walker 2004). There are many suitable backwaters along the Murray in South Australia, and regional mean temperatures exceed 15°C for 6-7 months in 75% of all years (Smith and Walker 2004). In 2001-2002, spawning was continuous over 9 months, from September to May, although most YOY carp were hatched in November and from mid-January to mid-March. Subsequently, spawning began in September 2002 and intensified in late October and November.

The absence of YOY carp in samples at Punyelroo in January and May 2002 probably reflects seasonally low water levels and a lack of submerged vegetation rather than a lack of spawning. Where littoral vegetation is absent, or made inaccessible by falling water levels, YOY carp are forced into deeper, open water where they cannot be sampled adequately using a small seine.

Other Australian studies report one short annual period of spawning. For example, the pioneering work of Hume *et al.* (1983¹) in Victoria suggested that carp spawned over 1-4 months, from mid-September to December. However, regular seine samples of YOY carp were obtained only from one lake, where there was 'very sparse aquatic vegetation' (Hume *et al.* 1983¹, p. 10). Macroscopic staging of gonads suggested additional spawning in January and March, and potentially earlier (July, August), but this was apparently discounted (Hume *et al.* 1983¹, p. 57: Figure 3.6). In subsequent studies, adequate YOY sampling occurred only over the presumed spring/summer period until February (Vilizzi 1998, Smith 1999⁴, Stuart and Jones 2002²). In one study where YOY samples were obtained monthly over 4 years (Humphries *et al.* 2002), and where a 1-4 month spawning period also was reported, the results may have been biased by concentrating most fishing effort in lotic environments, where carp spawning is minimal, and

¹ Smith, B. B. 1999. Observations on the early life history of carp, *Cyprinus carpio*: fecundity, spawning and tolerance of eggs to dehydration and salinity. BSc(Hons) Thesis, Department of Environmental Biology, The University of Adelaide. Unpublished, 32 p.

by using fishing methods (light traps, drift nets, plankton tow nets) that may be effective only when YOY carp are abundant (Smith and Walker 2004). More recent studies (Sivikumar *et al.* 2003; Smith and Walker 2004), plus observations by commercial fishers on the Murray (pers. comms: Keith Bell, K & C Fisheries; Henry Jones, Clayton; Shane Warrick, Walker Flat), argue for protracted spawning by carp, at least in south-eastern Australia.

The patterns of spawning and YOY survival observed here are consistent with studies of carp in other parts of the world. That is, spawning begins in spring after the gonads mature in winter and, where spawning is protracted over 4-5 months or more, each female spawns more than once (Alikunhi 1966; Swee and McCrimmon 1966; Shikshabekov 1972; Crivelli 1981; Horvath 1985; Davies *et al.* 1986; Brzuska 1989; Guha and Mukherjee 1991). Where multiple spawnings occur, 3-4 months are required for the gonads to re-mature (Davies and Hanyu 1986; Davies *et al.* 1986; Mills 1991). Thus, in this study, intense spawning was apparent from mid-October to December 2001 and again 3-4 months later, from mid-January to mid-March 2002. As the 'window of opportunity' for carp spawning in the lower Murray is about 6-7 months, based on their minimum temperature (15-16°C) and light (10-12) requirements (Smith and Walker 2004), most females probably spawn twice annually: once at onset and again after re-maturation of the gonads. The fact that spawning occurred over 9 months, rather than six, may be a consequence of variation in the timing of spawning in separated areas, mediated by pheromones which synchronise reproduction between cohabiting individuals (see Irvine and Sorensen 1993; Poling *et al.* 2001; Kobayashi *et al.* 2002). Clearly, this is speculative and needs further investigation.

Interpretations of spawning patterns for riverine fish may be confounded by larvae drifting in the main-channel, entrained out of upstream nursery habitat by high flows, if there is spatial variation in the timing of spawning. In this study, however, a closed population model is assumed because (a) the lower Murray is highly regulated by 9 weirs and their

associated navigable locks, and is akin to a series of stepped pools, (b) there were no appreciable flows during the period of sampling and (c) carp larvae are not known to disperse via the main-channel during low flows. Thus, we are confident of our description of carp spawning pattern for the lower River Murray.

Finally, this study argues for the utility of a dual approach to sampling, in that the shortfalls of one class of methods were offset by the merits of the other. Compared to the hatch-date estimates, data from gonad histology, GSI and cohort analyses failed to elucidate the timing or frequency of spawning. On the other hand, GSI data and ovary examinations indicated that spawning persisted until May 2002 and resumed in September 2002, where hatch-date data failed to identify reproductive activity. The former disparity might have been offset by increasing the number of monthly gonad samples; the latter is evidence for successful spawning but unsuccessful YOY survivorship. YOY survivorship may have been limited by the cooler conditions in late autumn (May) and early spring (September), as the food acquisition, metabolism and growth of larvae are strongly influenced by water temperatures (Houde 1987; Downing and Plante 1993; Hurst and Conover 1998; Hall and Rudstam 1999).

Acknowledgements

This paper is from PhD research by BBS, supported by grants from The University of Adelaide and the Cooperative Research Centre for Freshwater Ecology. We are grateful to Sandra Leigh, Kane Aldridge, Alex Ivey, Tamryn Herridge and Brenton Smith for assistance in sampling, and to Henry Jones (Clayton) and colleagues from state fishery agencies for collecting gonad samples. Gail Hermanis (Department of Anatomy & Histology, The University of Adelaide) and Sandra Leigh (South Australian Research & Development Institute, Aquatic Sciences Division) provided valuable advice on histological processing and interpretation. Finally, we thank three referees for providing helpful comments, which considerably strengthened the original manuscript.

References

- ALIKUNHI, K. H. 1966. Synopsis of biological data on common carp *Cyprinus carpio* Linnaeus, 1758 (Asia and the Far East). Food and Agriculture Organisation of the United Nations. FAO Department of Fisheries, Rome. 114 p.
- BEAMISH, R. J. & FOURNIER, D. A. 1981. A method for comparing the precision of a set of age determinations. *Canadian Journal of Fisheries and Aquatic Sciences* **38**: 982-83.
- BROWN, P., GREEN, C., SIVAKUMARAN, K. P., STOESSSEL, D. & GILES, A. 2004. Validating otolith annuli for annual age determination of common carp. *Transactions of the American Fisheries Society* **133**: 190-96.
- BRZUSKA, E. 1989. Investigations on controlled reproduction of carp (*Cyprinus carpio* L.) in early spring. *Acta Hydrobiologica* **31** (1/2): 121-9.

- CAMPANA, S. E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology* **59**: 197-242.
- CHANG, W. Y. B. 1982. A statistical method for evaluating the reproducibility of age determination. *Canadian Journal of Fisheries and Aquatic Sciences* **39**: 1208-10.
- CRIVELLI, A. J. 1981. The biology of the common carp, *Cyprinus carpio* L. in the Carmargue, southern France. *Journal of Fish Biology* **18**: 271-90.
- DAVIES, P. R. & HANYU, I. 1986. Effect of temperature and photoperiod on sexual maturation and spawning of the common carp I. Under conditions of high temperature. *Aquaculture* **51**: 277-88.
- _____, FURUKAWA, K. & NOMURA, M. 1986. Effect of temperature and photoperiod on sexual maturation and spawning of the common carp II. Induction of spawning by manipulating photoperiod and temperature. *Aquaculture* **52**: 137-44.
- DOWNING, J. A. & PLANTE, C. 1993. Production of fish populations in lakes. *Canadian Journal of Fisheries and Aquatic Sciences* **50**: 110-20.
- GUHA, D. & MUKHERJEE, D. 1991. Seasonal cyclical changes in the gonadal activity of common carp, *Cyprinus carpio* Linn. *Indian Journal of Fisheries* **38** (4): 218-223.
- HALL, S. R. & RUDSTAM, L. G. 1999. Habitat use and recruitment: A comparison of long-term recruitment patterns among fish species in a shallow eutrophic lake, Oneida Lake, NY, U.S.A. *Hydrobiologia* **408/409**: 101-113.
- HORVATH, L. 1985. Egg development (oogenesis) in the common carp (*Cyprinus carpio* L.). In 'Recent Advances in Aquaculture'. (Eds J. F. Muir & R. J. Roberts). pp. 31-77. (Croom Helm, London).
- HOUE, E. 1987. Fish early life dynamics and recruitment variability. *American Fisheries Society Symposium* **2**: 17-29.
- HUMPHRIES, P. & LAKE, P. S. 2000. Fish larvae and the management of regulated rivers. *Regulated Rivers: Research and Management* **16**: 421-432.
- _____, SERAFINI, L. G. & KING, A. I. 2002. River regulation and fish larvae: variation through space and time. *Freshwater Biology* **47**: 1307-31.
- HURST, T. P. & CONOVER, D. O. 1998. Winter mortality of young-of-the-year Hudson River striped bass (*Morone saxatilis*): Size-dependent patterns and effects on recruitment. *Canadian Journal of Fisheries and Aquatic Sciences* **55**: 1122-30.
- IRVINE, I. A. S. & SORESENSEN, P. W. 1993. Acute olfactory sensitivity of wild common carp, *Cyprinus carpio*, to goldfish hormonal sex pheromones is influenced by gonadal maturity. *Canadian Journal of Zoology* **71**: 2199-2210.
- KOBAYASHI, M., SORESENSEN, P. W. & STACEY, N. E. 2002. Hormonal and pheromonal control of spawning behaviour in the goldfish. *Fish Physiology and Biochemistry* **26**: 71-84.
- KOEIN, J., BRUMLEY, A. & GEHRKE, P. 2000. Managing the Impacts of Carp. Bureau of Rural Sciences, Canberra. 250 p.
- MILLS, C. A. 1991. Reproduction and life history. In 'Cyprinid fishes: Systematics, Biology and Exploitation'. (Eds I. J. Winfield & J. S. Nelson). pp. 483-509. (Chapman and Hall, London).
- PINSENT, D. A. & METHVEN, D. A. 1997. Protracted spawning of Atlantic cod (*Gadus morhua*) in Newfoundland waters: evidence from otolith microstructure. *Canadian Journal of Fisheries and Aquatic Sciences* **54** (Suppl. 1): 19-24.
- POLING, K. R., FRASER, E. J. & SORESENSEN, P. W. 2001. The three steroidal components of the goldfish pre-ovulatory pheromone signal evoke different behaviours in males. *Comparative Biochemistry and Physiology Part B* **129**: 645-51.
- SHIKHSHABEKOV, M. M. 1972. The annual cycle of the gonads in wild carp (*Cyprinus carpio* L.) from the Terek Delta. *Journal of Ichthyology* **5**: 855-9.
- SIGLER, W. F. 1958. The ecology and use of carp in Utah. Logan Agricultural Experiment Station Bulletin 405, Utah State University. Salt Lake City. 63 p.
- SMITH, B. B. & WALKER, K. F. 2003a. Shrinkage of 0+ carp (*Cyprinus carpio* L.) after preservation in ethanol. *Marine and Freshwater Research* **54** (2): 113-6.
- _____, & _____ 2003b. Validation of the aging of 0+ carp (*Cyprinus carpio* L.). *Marine and Freshwater Research* **54**: 1005-8.
- _____, & _____ 2004. Spawning dynamics of common carp in the River Murray, South Australia, shown by macroscopic and histological staging of gonads. *Journal of Fish Biology* **64**: 336-54.
- SPRANZA, J. J. & STANLEY, E. H. 2000. Condition, growth and reproductive styles of fishes exposed to different environmental regimes in a prairie drainage. *Environmental Biology of Fishes* **59**: 99-109.
- SWEE, U. B. & MCCRIMMON, H. R. 1966. Reproductive biology of the carp, *Cyprinus carpio* L., in Lake St. Lawrence, Ontario. *Transactions of the American Fisheries Society* **95** (4): 372-80.
- TREASURER, J. W. 1992. Length and weight changes in 0+ perch, *Perca fluviatilis* L., following fixation in formalin. *Journal of Fish Biology* **41**: 1033-36.
- VILIZZI, L. 1998. Age, growth and cohort composition of 0+ carp in the River Murray, Australia. *Journal of Fish Biology* **52**: 997-1013.

A COMPARISON AMONG THREE ARTIFICIAL SUBSTRATES FOR AQUATIC MACROINVERTEBRATE SAMPLING

BRIEF COMMUNICATION

Summary

Artificial substrate samplers (ASS) are a widely used method for collecting aquatic macroinvertebrates. They are most often used in large and deep rivers where other methods that directly sample the fauna may be difficult or impossible to apply^{1,2,3,4}. Different sampling methods may collect different subsets of the fauna from the same site. For example in several Australian lowland rivers, artificial substrates which collected colonising animals, airlift samples of the soft benthos and sweep samples of the edge habitat each collected different subsets of the total suite of macroinvertebrates within a site³. In south eastern Australia, a widely used ASS design is the onion-bag basket, which comprises a PVC 'gutter-guard' basket filled with two onion bags and a half a brick for ballast^{3,5}. A variation on this design, the two onion bags being replaced by three citrus bags, was adopted by the Floodplain Ecology Group for the preparation of the Integrated Watering Strategy series of reports (Floodplain Ecology Group unpub.).

BRIEF COMMUNICATION

A COMPARISON AMONG THREE ARTIFICIAL SUBSTRATES FOR AQUATIC MACROINVERTEBRATE SAMPLING

Artificial substrate samplers (ASS) are a widely used method for collecting aquatic macroinvertebrates. They are most often used in large and deep rivers where other methods that directly sample the fauna may be difficult or impossible to apply^{1,2,3,4}. Different sampling methods may collect different subsets of the fauna from the same site. For example in several Australian lowland rivers, artificial substrates which collected colonising animals, airlift samples of the soft benthos and sweep samples of the edge habitat each collected different subsets of the total suite of macroinvertebrates within a site⁵. In south eastern Australia, a widely used ASS design is the onion-bag basket, which comprises a PVC 'gutter-guard' basket filled with two onion bags and a half a brick for ballast^{3,5}. A variation on this design, the two onion bags being replaced by three citrus bags, was adopted by the Floodplain Ecology Group for the preparation of the Integrated Watering Strategy series of reports (Floodplain Ecology Group unpub.).

The aim of this study was to determine if there was any significant difference in macroinvertebrate abundance, taxa richness and community composition between ASS with different internal substrates. A third filling, 'flywire' was also trialled to determine if it differed to the other two substrates in the aforementioned characteristics. ASS with the three types of substrate were deployed at two sites; one upland, the Broken River at Bridge Creek (36° 06' 00" 145° 41' 00"; altitude, 330 masl) and one lowland, the Broken Creek downstream of Nathalia (36° 02' 30" 145° 06' 35"; altitude, 90 masl) in Victoria.

The ASS were constructed using the same basic design as described in Humphries *et al.*³ and Bennison *et al.*⁵. 'Gutterguard' baskets (mesh size 10 x 10 mm; 180 mm high x 180 mm base diameter) were filled with one of three fillings. The 'onion' bag samplers were filled with two double sided knitted nylon onion bags (each 350 x 770 mm, 2x2 mm mesh), the 'citrus' bag samplers were filled with three double sided nylon citrus bags (each 205 x 540 mm, 5x5 mm mesh) and the 'flywire' samplers were filled with three sheets of flyscreen (each 200 x 1000 mm, 1 x 1 mm mesh).

Ten samplers of each type were deployed in the field for six weeks (22 February-6 April 1995) to be consistent with the monitoring carried out by Bennison *et al.*⁵ and the Integrated Watering Strategy (Floodplain Ecology Group unpub.). Half a house brick, or a similar sized rock was used as ballast. For the bag samplers, the brick was placed inside one of the bags and the bag was wrapped tightly around the brick. This bundle was then placed inside another bag which was wrapped around the bundle. This process was repeated for the remaining bag. The flywire sheets were wrapped tightly around the brick, one upon the other. The brick and filling bundle was placed in the basket and the top of the basket was sewn closed with the nylon cord used to anchor the ASS. The ASS were placed in pools at a depth of approximately 1 m, parallel to the bank, out of the main force of the current. Samplers were deployed by tying them

to stream side trees or to stakes hammered into the edge of the stream.

The ASS were retrieved by placing a 250 µm dipnet downstream of, and then under, the ASS as it was picked up and removed from the water. The basket was opened and cleaned in the net. Each piece of substrate (onion, citrus or flywire) was scrubbed thoroughly and examined for attached invertebrates before being removed from the net. Once all invertebrates had been removed from the basket, substrate and ballast, the sample was preserved in 70% ethanol. In the laboratory the invertebrates were sorted from the detritus, identified to the lowest taxonomic level practicable (usually genus or species) and counted.

Differences in macroinvertebrate abundance and taxa richness were compared using a two factor ANOVA, with site as a random factor and substrate type as a fixed factor. Data were log transformed prior to analysis. Post hoc comparisons were undertaken using a Tukey HSD test. Differences in the macroinvertebrate communities collected from the two sites by the three substrates were analysed using a two way crossed ANOSIM procedure⁶ in the PRIMER software package⁷. Species which had the greatest contributions to any significant ANOSIM sample divisions were identified using the similarity percentages program (SIMPER) in PRIMER. The Bray-Curtis association measure was used for log-transformed abundance data.

A significantly greater mean number of macroinvertebrates were collected from the Broken River than from the Broken Creek ($F_{1,54}=15.92$, $p<0.001$; Fig. 1a). Significant differences were also observed among mean invertebrate abundance collected from the different substrate types ($F_{2,54}=48.50$, $p<0.001$). The onion substrates collected more invertebrates than either the citrus or flywire substrates, whilst the flywire collected more macroinvertebrates than the citrus substrates. There was no interaction between site and substrate type ($F_{2,54}=2.108$, $p=0.131$; Fig. 1a).

Artificial substrates collected significantly greater numbers of macroinvertebrate taxa from the Broken River than from the Broken Creek ($F_{1,54}=16.312$, $p<0.001$). There was no significant difference in taxa richness among substrates ($F_{2,54}=0.846$, $p=0.435$) nor a significant interaction effect ($F_{2,54}=0.084$, $p=0.919$; Fig. 1b). ANOSIM results revealed differences in macroinvertebrate community composition between sites ($R=0.981$, $p<0.001$) and substrate types ($R=0.240$, $p<0.001$).

SIMPER analysis revealed fifty percent of the dissimilarity of samples between sites was explained by the empheropterans *Atalophlebia* sp 3/13 and *Koorrnoonga* sp A2, and the trichopteran *Ecnomus cygnitus* Neboiss being found only in the Broken River; whilst *Ecnomus pansus* Neboiss was found only in the Broken Creek. The chironomids *Chironomus* sp. and *Procladius* sp. and the yabbie *Cherax* sp. were found in higher average abundances in the Broken Creek than the Broken River.

A range of invertebrates explained the dissimilarity

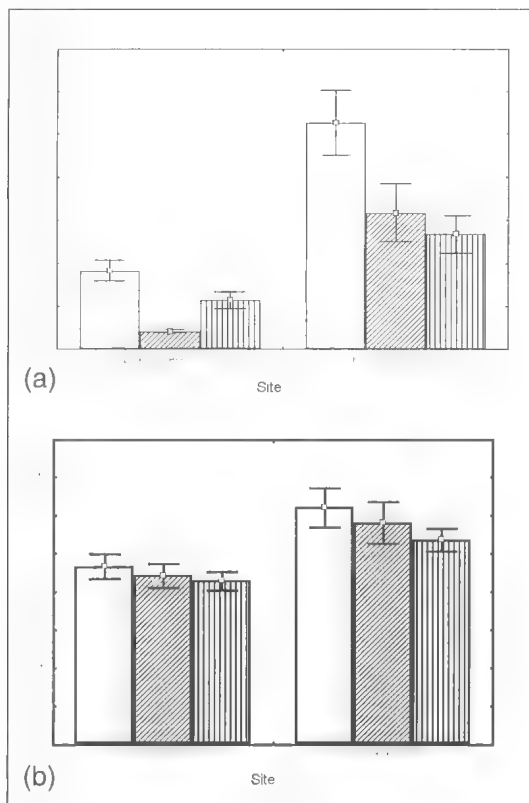


Fig. 1. Mean (\pm SE) macroinvertebrate abundance (a) and taxa richness (b) for the onion (clear bars), citrus (diagonal lines) and flywire (vertical lines) artificial substrate fillings collected from the Broken Creek and Broken River.

between communities found in the different substrates. Those that explained more than fifty percent of the dissimilarity for all three substrates at the Broken Creek were the chironomids *Chironomus* sp., *Parachironomus* sp. and *Dicoretendipes* sp., for which greater average abundances were collected from the onion substrates than either the flywire or citrus substrates. *Chironomus* sp. was more abundant in the flywire than the citrus substrates whilst the opposite was the case for *Parachironomus* sp. A higher average abundance of the ephemeropteran *Tasmanocoenis* sp. was found in the citrus substrates than either the onion or flywire substrates, whilst the onion substrates had a higher abundance than the flywire substrates.

At the Broken River, the flywire substrates collected greater average abundances of *Chironomus* sp., *Oligochaeta* and the water bug *Anisops* sp. than either the onion or citrus substrates. For all of these cases the citrus substrates had a higher average abundance than the onion substrates. Greater

average abundances of *Atalophlebia* sp 3/13, immature leptophlebiids, *Ecnomus cygnitus*, and the beetle *Antiporus* sp. were collected from the onion substrates than either of the other two. The citrus substrates collected more of these invertebrates than the flywire substrates except for *Atalophlebia* sp 3/13, where flywire collected more than citrus. More psphenids were collected from the citrus substrates than the onion or flywire substrates, whilst the onion substrates collected more than the flywire substrates.

The three artificial substrate fillings collected distinct macroinvertebrate communities in different abundances from within separate sites. However differences between samplers were less than differences between sites. Differences in invertebrate abundance collected from the three substrate types are most likely due to differences in the surface area available for colonisation. For example the close weave and coarse fibres of the onion-bag, combined with its double surface (total surface area 1.07 m²), provided a greater area of habitat for colonisation than either the single sheets of flywire (0.42 m²) or the open fine weave of the citrus-bags (0.60 m²). That there was a difference in the macroinvertebrate communities found to colonise each of the three substrates was unexpected, as in a study of four Australian lowland rivers very similar communities were found to be collected using either onion-bag samplers or 0.5 m lengths of Red Gum (*Eucalyptus camaldulensis* Dehnh.), a sampling device much less similar to the onion-bag sampler than either of the two alternative substrates used in this study. Although the substrates collected distinct invertebrate communities within a site they were similar enough to be able to differentiate between sites. If invertebrate abundance or community composition is the parameter of interest then different substrates should not be used interchangeably. However invertebrate richness can be assessed with any of the substrate fillings.

This project was funded as a part of EPV 1 Monitoring River Health Initiative Victorian Programme b) evaluation of artificial substrate sampling with rapid bioassessment. Keith Ward, Rhonda Butcher, Garry Bennisson, Tracy Clark and Alex McNee are thanked for their help and guidance. Richard Marchant and Leon Metzeling are thanked for their constructive comments on earlier drafts of this paper.

'De Pauw, N., Lambert, V., Van Kenhove, A. & Bij De Vaate, A. (1994) *Environ. Monit. Assess.* **30**, 25-47.

'Hellawell, J. M. (1978) "Biological Surveillance of Rivers. A Biological Monitoring Handbook" (Dorset Press, Dorchester).

'Humphries, P., Gowns, J. E., Serafini, L. G., Hawking, J. H., Chick, A.J. & Lake, P.S. (1998) *Hydrobiologia* **364**, 209-218.

'Rosenberg, D. M. & Resh, V. H. (1982) The use of artificial substrates in the study of freshwater benthic macroinvertebrates pp 175-235 *In* Cairns Jr. J. (Ed) "Artificial Substrates" (Ann Arbor Science Publishers Inc., Ann Arbor).

'Bennisson, G. L., Hillman, T. J. & Suter, P. J. (1989) "Macroinvertebrates of the River Murray (Survey and Monitoring: 1980-1985)" (Water Quality Report No 3. Murray-Darling Basin Commission, Canberra).

'Clarke, K. R. (1993) *Aust. J. Ecol.* **18**, 117-143.

'Clarke, K. R. & Warwick, R. M. (1994) "Change in marine communities: an approach to statistical analysis and interpretation" (Natural Environment Research Council, UK).

NEW SYNONYMY AND NEW NAMES IN AUSTRALIAN TENEBRIONIDAE (COLEOPTERA)

BRIEF COMMUNICATION

Summary

The following new synonymy is proposed: *Paratoxicum* Champion 1894 = *Schizophthalmotribolium* Kaszab 1940; *Mithippia aurita* Pascoe, 1869 = *Tarpela catenulata* Allard, 1877; *Cheirodes sardous* Gené, 1839 = *Anemia caulobioides* Carter 1920. New replacement names are proposed to for eight homonyms: *Cyphaeus carteri* n.n. for *C. formosus* (Carter, 1927) not *C. formosus* Westwood, 1841; *Cyphaeus georgemastersi* n.n. for *C. mastersi* (Macleay, 1872) not *C. mastersi* Pascoe, 1871; *Nyctozoilus macleayanus* n.n. for *N. macleayi* Carter, 1926 not *N. macleayi* (Bates, 1872); *Nyctozoilus carteri* n.n. for *N. marginicollis* (Carter, 1909) not *N. marginicollis* (Bates, 1872); *Nyctozoilus geomastersi* n.n. for *N. mastersi* (Carter 1909) not *N. mastersi* Macleay, 1872; *Nyctozoilus obesulus* n.n. for *N. obesus* (Carter, 1933) not *N. obesus* Guérin, 1830; *Nyctozoilus jaystepheni* n.n. for *N. stepheni* (Carter, 1914) not *N. stepheni* (Carter 1909); *Ulomoides carteri* n.n. for *U. macleayi* (Carter 1926) not *U. macleayi* Carter, 1926.

BRIEF COMMUNICATION

NEW SYNONYMY AND NEW NAMES IN AUSTRALIAN TENEBRIONIDAE
(COLEOPTERA)

The following new synonymy is proposed: *Paratoxicum* Champion, 1894 = *Schizophthalmotribolium* Kaszab, 1940; *Mithippia aurita* Pascoe, 1869 = *Tarpela catenulata* Allard, 1877; *Cheirodes sardous* Gené, 1839 = *Anemia caulobioides* Carter, 1920. New replacement names are proposed for eight homonyms: *Cyphaleus carteri* n.n. for *C. formosus* (Carter, 1927) not *C. formosus* Westwood, 1841; *Cyphaleus georgemastersi* n.n. for *C. mastersi* (Macleay, 1872) not *C. mastersi* Pascoe, 1871; *Nyctozoilus macleayanus* n.n. for *N. macleayi* Carter, 1926 not *N. macleayi* (Bates, 1872); *Nyctozoilus carteri* n.n. for *N. marginicollis* (Carter, 1909) not *N. marginicollis* (Bates, 1872); *Nyctozoilus geomastersi* n.n. for *N. mastersi* (Carter, 1909) not *N. mastersi* Macleay, 1872; *Nyctozoilus obesulus* n.n. for *N. obesus* (Carter, 1933) not *N. obesus* Guérin, 1830; *Nyctozoilus jaystepheni* n.n. for *N. stepheni* (Carter, 1914) not *N. stepheni* (Carter, 1909); *Ulomoides carteri* n.n. for *U. macleayi* (Carter, 1926) not *U. macleayi* Carter, 1926.

While the author was preparing an online checklist of the Australian Tenebrionidae for the Australian Faunal Directory, Australian Biological Resources Study, eight homonyms were found to have resulted from previous taxonomic mergers of generic names, as listed below. At the same time, the opportunity is taken to propose one generic and two specific synonymies resulting from recent examination of types in Hungary and Germany.

The four-letter codens below refer to institutions in which types are deposited, as follows: AMSA – Australian Museum, Sydney; BMNH – The Natural History Museum, London; HNHB – Hungarian Natural History Museum, Budapest; MVMA – Museum of Victoria, Melbourne; ZSSM – Zoologische Staatssammlung, Munich.

The author thanks Dr Martin Baehr at ZSSM for financial assistance and the Australian Biological Resources Study for supporting the work on Tenebrionidae.

Synonymy

Paratoxicum Champion, 1894: 380.

= *Schizophthalmotribolium* Kaszab, 1940: 173. **New synonymy.**

Type species: *Paratoxicum iridescens* Champion, 1894, by monotypy. Syntypes in BMNH, not examined.

Schizophthalmotribolium australiae Kaszab, 1940, by monotypy. Holotype in HNHB, examined.

Mithippia Pascoe, 1869: 293.

aurita Pascoe, 1869: 293. Adelaide, SA. Holotype in BMNH, examined.

= *catenulata* (Allard, 1877: 97) (*Tarpela*). Australia. Holotype in ZSSM, examined. **New synonymy.**

Cheirodes Gené, 1839: 73.

sardous Gené, 1839: 73. Sardinia. Type not located.

= *caulobioides* (Carter, 1920: 224) (*Anemia*). Swan R.,

Perth, WA. Syntypes AMSA, MVMA, examined. **New synonymy.**

Homonymy

In the following list, homonyms in *Cyphaleus* and *Nyctozoilus* result from the synonymisation of Matthews¹ of a number of generic names in the subtribe Cyphaleina (Heleini), while the homonym in *Ulomoides* is the result of the transfer of *Platydema macleayi* Carter to the genus *Ulomoides* by Doyen *et al.*²

Cyphaleus Westwood, 1841: 43.

carteri **new name** for *C. formosus* (Carter, 1927: 33) (*Oremasis*) not *C. formosus* Westwood, 1841: 43.

georgemastersi **new name** for *C. mastersi* (Macleay, 1872: 287) (*Chartopteryx*) not *C. mastersi* Pascoe, 1871: 357.

Nyctozoilus Guérin-Méneville, 1830: pl. 4, fig. 2.

macleayanus **new name** for *N. macleayi* Carter, 1926: 511 not *N. macleayi* (Bates, 1872: 276) (*Hypocilibe*).

carteri **new name** for *N. marginicollis* (Carter, 1909: 136) (*Aethalides*) not *N. marginicollis* (Bates, 1872: 277) (*Onosterrhus*).

geomastersi **new name** for *N. mastersi* (Carter, 1909: 139) (*Byallius*) not *N. mastersi* Macleay, 1872: 284.

obesulus **new name** for *N. obesus* (Carter, 1933: 169) (*Onosterrhus*) not *N. obesus* Guérin-Méneville, 1830: pl. 4, fig. 2.

jaystepheni **new name** for *N. stepheni* (Carter, 1914: 379) (*Aethalides*) not *N. stepheni* (Carter, 1909: 133) (*Agasthenes*).

Ulomoides Blackburn, 1887: 274.

carteri **new name** for *U. macleayi* (Carter, 1926: 68) (*Platydema*) not *U. macleayi* Carter, 1926: 67.

¹Matthews, E. G. (1992). Classification, relationships and distribution of the genera of Cyphaleini (Coleoptera: Tenebrionidae). *Invertebr. Taxon.* 6: 437–522.

²Doyen, J. T., Matthews, E. G. and Lawrence, J. F. (1990). Classification and annotated checklist of the Australian genera of Tenebrionidae (Coleoptera). *Invertebr. Taxon.* 3 [1989]: 229–260.

REFEREES

The Editor wishes to thank the following colleagues who have scrupulously refereed papers for the journal. He apologises for any inadvertent omissions. Without peer review, scientific journals could not function, yet this essential role frequently goes unacknowledged.

John Arnould
 Tony Auld
 Andy Austin
 Odile Bain
 Michael Balcke
 Ian Beveridge
 Andrew Boulton
 Alan Brownlee
 Graham Cam
 Gordon Carmichael
 Peri Coleman
 John Conran
 Tom Cribb
 Ross Crozier
 John Dixon
 Rod Fensham
 Martin Gomon
 Brent Henderson
 Lars Hendrich

Mike Hodda
 Tony Howes
 Muhammad Iqbal
 John Jennings
 Hugh Jones
 Bernhard Klausnitzer
 Jeff Knott
 Michael Kokkin
 Gerry Kraft
 Philip Leppard
 John Ling
 Ian Linnane
 Sam McClatchie
 Alan McKay
 Chris Madden
 Michael Mahony
 Eric Matthews
 Geoff Monteith
 Margie Morrice

Sue Murray-Jones
 Ian Naumann
 Jackie Nobbs
 Bob Parsons
 John Pollard
 Tarmo Raadik
 Stephen Richards
 Ian Riley
 Bayden Russell
 Peter Shaughnessy
 Adam Slipinski
 Dave Spratt
 John Sved
 Klaus Ullrich
 Peter Unmack
 Lesley Warner
 Hiroyuki Yoshitomi
 Wolfgang Zeidler

ROYAL SOCIETY OF SOUTH AUSTRALIA INCORPORATED

Patron:

HER EXCELLENCY MARJORIE JACKSON-NELSON, AC, MBE
GOVERNOR OF SOUTH AUSTRALIA

OFFICERS FOR 2003-2004

President:

O. W. WIEBKIN, BSc, PhD

Vice-Presidents:

R. W. FITZPATRICK, BSc Agric, MSc Agric, PhD
N. F. ALLEY, BA(Hons), MA, PhD

Secretary:

J. H. LOVE, BA, BD

Minutes Secretary:

N. F. MORCOM, BSc(Hons), PhD

Editor:

O. MAYO, BSc(Hons), PhD, DSc, FAA, FTSE

Treasurer:

J. T. JENNINGS, BSc(Hons), PhD

Editorial Board:

P. CLARKE

R. HILL

J. JENNINGS

K. LEE

O. MAYO

I. RILEY

Programme Secretary:

N. J. SOUTER, BSc(Hons)

Membership Secretary:

A. J. McARTHUR, OAM, BE

Librarian:

Members of Council:

J. E. PATTISON, MA, BSc, MSc, Grad Cert Ed

P. A. PARSONS, BAgSc, PhD, ScD, FLS

R. D. SHARRAD, BSc(Hons), PhD, DipT(Sec)

M. IQBAL, BSc(Hons), MSc, PhD

M. A. J. WILLIAMS, BA(Hons), MA, PhD, ScD